EU EDF 8 – SOPAC Project Report 69d:
Reducing Vulnerability of Pacific ACP States

SAMOA TRAINING REPORT

CAPACITY BUILDING IN FLOOD RISK MANAGEMENT – TRAINING IN FLOOD HYDROLOGY, RIVER MODELLING AND FLOODPLAIN MAPPING

13th July – 3rd August 2006

Course participants setting up the HEC HMS software.

HR Wallingford
Working with water

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October 2008

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IMPORTANT NOTICE

This report has been produced with the financial assistance of the European Community; however, the views expressed herein must never be taken to reflect the official opinion of the European Community.

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TABLE OF CONTENTS

ACKNOWLEDGEMENTS 4
EXECUTIVE SUMMARY 5
1 INTRODUCTION 6
2 COURSE PARTICIPANTS 6
Participants 6
Resource Personnel 7
3 TRAINING PROGRAMME 7
4 COURSE MATERIAL 7
5 FEEDBACK AND EVALUATION 7
6 OUTLOOK 8
7 CONCLUSION AND RECOMMENDATIONS 8

APPENDICES

A Detailed Training Programme 10
B Daily Schedule of Activities 12
C Completed Training Evaluation Forms (digital distribution only)
D Training Examination Questions (digital distribution only)
E Training Slides (digital distribution only)
F Exercises (digital distribution only)
G Glossary of Terms (digital distribution only)

ACKNOWLEDGEMENTS

The European Commission provided funding for this project task under the framework of the SOPAC/EU Reducing Vulnerability Project. Additional funding was kindly provided by the EU-funded Samoan Water Sector Strengthening Program (WaSSP) and the SOPAC Water Sector.

The work was carried out in close cooperation with the Ministry for Natural Resources, Environment and Meteorology (MNREM), and appreciation for managerial support goes to Ausetalia Titimaea (Meteorology), Amataga Penaia (Water Resource) and Nadia Meredith (WaSSP manager).

Special thanks to Silver Yance, flood-modelling consultant of the ADB project for the very helpful co-operation and the exchange of data and model results.

EXECUTIVE SUMMARY

Floods are a well-recognised risk in Samoa frequently causing major damage. The floods in April 2001 alone caused an estimated 11 Million Tala in direct losses. The aim of this project task is to build capacity in flood management to reduce future losses by strengthening the capacity of technical agencies in flood forecasting, mapping and mitigation.

This report summarises the training efforts by a joint HR Wallingford / SOPAC team working together with technical specialists from the Ministry of Natural Resources, Environment and Meteorology to produce flood hazard maps of the Vaisigano River in Apia. During the first of two visits by the flood-modelling specialist of HR Wallingford special emphasis was given on providing baseline knowledge in flood hydrology, river modelling and floodplain mapping. An introduction in two widely used flood modelling freeware packages was provided, enabling the course participants to set up a simple computer model of the Vaisigano River. During the next visit in November 2006 the model will be developed further to produce flood hazard maps and flood risk estimates as basis for the development of flood mitigation options and flood management guidelines.

Improving flood prediction and water resource management requires long-term, sustainable investment, not only in improving and maintaining the hydro-meteorological network, but also in increasing the capacity of the MNREM's Hydrology and Meteorology Division not only in data collection, but also in data maintenance, quality control and analysis.

The extensive training material provided to the course participants forms part of this report in appendices E to G. Details on the technical findings and the river cross-section survey are provided in separate reports.

1 INTRODUCTION

The training in flood hydrology, river modelling and floodplain mapping is part of an initiative to build capacity in flood management, including forecasting, monitoring modelling and mitigation within the technical agencies of the Government of Samoa. The aim is to take the participants through the whole process of acquiring, analysing and interpreting necessary datasets (hydro-meteorological and topography), which provide the input for flood models, to run the models and produce flood risk maps as a basis for the development of appropriate flood mitigation options.

The development of flood risk maps, flood forecasting, flood mitigation options and flood management guidelines will be part of the next training component planned for November 2006.

Darren Lumbroso, flood modelling and water resource specialist from HR Wallingford, UK, assisted by SOPAC staff delivered the training between 12 July 2006 and 3 August 2006 in the MNREM conference room in Apia. The course participants brought their own computers and laptops to the training, and the modelling software HEC-HMS and HEC-RAS had been installed on these computers.

2 COURSE PARTICIPANTS

The training was the first of its kind for all course participants. The participants brought a variety of skills to the training ranging from weather forecasting, hydrological data collection to environmental management. Participants were also required to have a strong science background, with good math, physics and computer skills. Specific knowledge in flood hydrology and river hydraulics was missing. In general the knowledge base in hydrology, modelling and water resources management is currently relatively weak at a technical level. Only Sala Sagato (Meteorology) had some university level education in hydrology and Iosefatu Eti and Masina Ngau Chun (Water Resource) have baseline training in hydrology and hydrometry. Participants at the course are listed below:

Participants

Mr Sala Sagato	Principal Officer, Weather, Meteorology Division
Mr Iosefa Aiolupotea	Strategic Planning Officer, PUMA
Mr Tumau Peni	Sustainable Development Officer, PUMA
Mr Iosefatu Eti	Hydrology Officer, Water Resources Division
Ms Masina Ngau Chun	Senior Scientific Officer, Water Resources Division
Ms Litea Biukoto	SOPAC (GIS Resource Person)
Ms Alena Lawedrau-Moroca	SOPAC (Hydrology Resource Person)

Training Coordinator

Mr Darren Lumbroso	HR Wallingford, UK
Mr Michael Bonte-Grapentin	SOPAC, Fiji

3 TRAINING PROGRAMME

The training was delivered in three different forms:

- formal lectures and exercises;
- data gathering and work on individual assignments; and
- joint development of hydrological and hydraulic model for Vaisigano River.

The formal training was undertaken over a period of five and a half days. The training course was developed using material that has been tried and tested by HR Wallingford Ltd over a number of years. It should be noted that considerable effort was made to modify the material to make it specifically relevant to the South Pacific and Samoa. A breakdown of the formal lectures and exercises is given in Appendix A and a daily schedule of activities is provided in Appendix B.

It is important to note that between Monday, 17 July 2006 and Friday, 21 July 2006; the participants used the knowledge they had gained on the flood hydrology course to work with Darren and Michael in analysing the flood hydrology of the Vaisigano River catchment. Between Friday, 28 July 2006 and Wednesday, 3 August 2006 the participants on the course used the skills they had acquired to commence constructing a one-dimensional HEC-RAS hydraulic model of approximately 1.6 km of the Vaisigano River upstream of its mouth at Apia Harbour.

4 COURSE MATERIAL

As part of the training, comprehensive sets of source material and lecture notes were provided to the course participants as hard and partly as softcopies:

- A comprehensive set of training notes comprising:
  - a glossary of key terms used in flood risk management (Appendix G);
  - colour copies of all the slides used for the presentations (Appendix F);
  - the material required for the training exercises; and
  - several papers relevant to hydrological and hydraulic modelling in the South Pacific.
- Copies of the HEC-HMS hydrological and HEC-RAS river-modelling software.
- Several copies of the HEC-HMS and HEC-RAS user and technical reference manuals, together with their application guides.

A copy of the training notes and exercises that were given to the participants is provided in appendices E and F.

5 FEEDBACK AND EVALUATION

At the end of the formal training period an evaluation form was distributed to assess the effectiveness of the training from the perspective of the participants. The training forms were filled in anonymously at a time when the course co-ordinators were not present in the training room. Copies of the completed training evaluation forms are included in Appendix C of this report. A total of seven participants filled in the evaluation form. All the participants indicated that the general content of the training was about what they had expected and rated the overall assessment of the training as “excellent”. Of the participants who responded five stated that the training would allow them to undertake their work related to flood hydrology, river modelling and flood risk management “much more effectively” in the future with one stating that it would allow them to undertake these duties “slightly more effectively”.

Many of the participants indicated that they had found the course and exercises “challenging”. The general feedback was summed up well by one participant who wrote:

"*Overall the training was an eye opener for me. I was able to learn more stuff that would enhance my duties at work. The lecture material, as well as the exercises, were well prepared and easy to understand. The exercises were a good form of practice putting the theory aspects to work*."

The majority of the participants indicated that in future they would like more training in the use of the hydrological modelling software HEC-HMS and the hydraulic modelling software HEC-RAS.

6 OUTLOOK

The training in the use of these software packages will be continued during second visit of the HR Wallingford/SOPAC team, which is likely to take place in November 2006. This training will not be as "formalised" as during the first visit. The training will take the form of the completion of a hydraulic model of around 2 km of the Vaisigano River. This model will be constructed, calibrated using available data on historical floods and then used to estimate design flood levels for the Vaisigano in the vicinity of Apia by each of the participants. Flood maps will also be produced and flood risk either in terms of direct economic damage or injuries to people will be estimated. Further, flood mitigation options will be evaluated and flood management guidelines will be produced.

7 CONCLUSION AND RECOMMENDATIONS

There is a need for sustained capacity building over a minimum of a five-year period within both the MNREM's Hydrology Unit and Meteorology Division. This should take a number of forms – from members of staff being funded to carry out relevant masters and bachelors' degree studies to shorter more focused courses, such as the one just delivered. It was interesting to note that on the evaluation forms filled out by the participants on the completed course, many wanted to focus on learning how to use the hydrological and hydraulic modelling software. It is also important to note that before these tools can be used effectively a firm grasp of the theory that underlies them is required. Therefore it is recommended that further training in basic hydrological and hydraulic concepts is undertaken before further training is given on the use of specific software tools.

APPENDIX A

Detailed Training Programme

Thursday 13 July 2006	**Flood hydrology**
9:00 – 9:30	Introduction to the training
9:30 – 10:00	Processes and definitions
10:00 – 10:30	Precipitation and runoff
10:30 – 11:00	Exercise
11:00 – 11:15	Break
11:15 – 11:45	Rating curves
11:45 – 12:30	Exercise
12:30 – 13:30	Lunch
13:30 – 14:00	Flood flow estimation using statistical methods
14:00 – 15:00	Exercises
15:00 – 15:15	Break
15:15 – 15:45	Rainfall-runoff methods
15:45 – 16:45	Exercise
16:45 – 17:00	Overview of day

Friday 14 July 2006	**Flood hydrology**
9:00 – 9:15	Introduction to the day
9:15 – 10:00	Introduction to the HEC-HMS modelling system
10:00 – 11:00	Exercises using HEC-HMS modelling system
11:00 – 11:15	Break
11:15 – 12:30	Exercises using HEC-HMS modelling system
12:30 – 13:30	Lunch
13:30 – 16:30	Field visit with SOPAC and MNREM to demonstrate flow gauging in the River Vaisigano River at Alaoa East gauging station on the Vaisigano River

Monday 24 July 2006	**River modelling and flood mapping**
9:00 – 9:15	Introduction to the day
9:15 – 9:45	Concepts and principles in hydraulics
9:45 – 10:30	Exercise
10:30 – 11:00	Introduction to river modelling
11:00 – 11:15	Break
11:15 – 12:30	Exercises
12:30 – 13:30	Lunch
13:30 – 14:00	River resistance and roughness
14:00 – 14:30	Exercise
14:30 – 15:00	Floodplain mapping
15:00 – 15:15	Break
15:15 – 16:15	Exercises
16:15 – 16:30	Overview of day

Tuesday 25 July 2006 **River modelling and flood mapping**

9:00 – 9:15	Introduction to the day
9:15 – 9:45	River morphology
9:45 – 10:30	Exercise
10:30 – 11:00	Methods of flood defence
11:00 – 11:15	Break
11:15 – 12:30	Exercise
12:30 – 13:30	Lunch
13:30 – 14:00	Risk, uncertainty and error
14:00 – 14:30	Exercise
14:30 – 15:00	Introduction to HEC-RAS river modelling software
15:00 – 15:15	Break
15:15 – 16:30	Exercise using HEC-RAS
16:45 – 17:00	Overview of the day

Wednesday 26 July 2006 **Use of HEC-RAS modelling software**

9:00 – 9:15	Introduction to the day
9:15 – 10:00	Exercise to develop a steady-state HEC-RAS river model
10:00 – 11:00	Exercise to illustrate the hydraulic modelling of bridges
11:00 – 11:15	Break
11:15 – 12:30	Exercise to demonstrate unsteady flow modelling in the HEC-RAS river modelling software
12:30 – 13:30	Lunch
13:30 – 14:30	Exercise to demonstrate how the deposition of sediment can be modelled using the HEC-RAS river modelling software
14:30 – 15:30	Exercise to show how weir structures can be modelled using the HEC-RAS software
15:30 – 16:30	Development of a HEC-HMS hydrological model of the catchment to produce design hydrographs

Thursday 27 July 2006 **Combining HEC-HMS and HEC-RAS modelling software**

9:00 – 9:15	Introduction to the day
9:15 – 10:30	Use of the design hydrographs from HEC-HMS with HEC-RAS to produce flood levels
10:30 – 10:45	Break
10:45 – 12:30	Exercise to test the knowledge gained by the participants over the previous five and half days training

APPENDIX B

Daily Schedule of Activities

Wed	12 July	2pm meeting with Samoan Water Resources Division, Hydrological Unit, and Darren Lumbroso, HR Wallingford consultant out of the UK
Thur	13 July	Hydrology training course
Fri	14 July	Hydrology training course
Weekend		
Mon	17 July	River modelling and floodplain mapping training
Tue	18 July	River modelling and floodplain mapping training
Wed	19 July	Review of available hydro-meteorological data/Introduction to HEC HMS
Thur	20 July	Review of available hydro-meteorological data/Introduction to HEC HMS
Fri	21 July	Statistical analysis of available flow data for the Vasigano catchment/Investigation of a regional flood frequency approach
Weekend		
Mon	24 July	Development of rainfall-runoff hydrographs for the Vasigano catchment
Tue	25 July	Development of rainfall-runoff hydrographs for the Vasigano catchment
Wed	26 July	Introduction to HEC-RAS and initial development of HEC RAS river model
Thur	27 July	Development of HEC-RAS river model
Fri	28 July	Development of HEC-RAS river model for the Vaisigano catchment
Weekend		
Mon	31 July	Development of HEC-RAS model for the Vaisigano catchment
Tue	1 Aug	Run HEC-RAS model for design flows
Wed	2 Aug	Start flood mapping
Thur	3 Aug	Continue flood mapping

APPENDIX C

Completed Training Evaluation Forms

[Appendices C to G available only in digital format]

Appendix C Completed training evaluation forms

TRAINING EVALUATION FORM
Training in flood hydrology, river hydraulics and flood mapping

Was the general content of the training about what you had expected? ☑ Yes ☐ No

How do you think the training will help you carry out any work related to flood hydrology, river modelling and flood risk management in the future?

☑ Much more effectively ☐ Slightly more effectively ☐ The same as before

Did you rate the speakers as ☑ Good ☐ Reasonable ☐ Poor?

Were the presentations ☐ Too technical ☑ About right ☐ Not technical enough?

What was your overall assessment of the training ☑ Excellent ☐ Good ☐ Reasonable ☐ Poor?

What was your assessment of the training material ☑ Excellent ☐ Good ☐ Reasonable ☐ Poor?

How did you find the training exercises ☐ Too challenging ☑ About right ☐ Too easy?

What were the strengths and weaknesses of the training?

- weakness
* ~~Not~~ participants from other sector not able to turn up
*
* not enough examples for ~~pers~~ onal/Group HWK.

- strength
* Hard copy materials well understand
* Very good examples (need more)
*

What areas of flood hydrology, river modelling and flood risk management do you think should we concentrate on during the next training and practical sessions in October 2006?

- I would suggest ~~to~~ add a component that will include extracting of precip information from meteorological models. Some meteorological models can give hourly rainfall with a few ~~days~~ too find out the hourly precip.

What other training in the fields of hydrology, river modelling and water resources management would assist you in carrying out your work more effectively?

- flood forecasting & flood risk management

TRAINING EVALUATION FORM
Training in flood hydrology, river hydraulics and flood mapping

Was the general content of the training about what you had expected? ☑ Yes ☐ No

How do you think the training will help you carry out any work related to flood hydrology, river modelling and flood risk management in the future?

☑ Much more effectively ☐ Slightly more effectively ☐ The same as before

Did you rate the speakers as ☑ Good ☐ Reasonable ☐ Poor?

Were the presentations ☑ Too technical ☐ About right ☐ Not technical enough?

What was your overall assessment of the training ☑ Excellent ☐ Good ☐ Reasonable ☐ Poor?

What was your assessment of the training material ☑ Excellent ☐ Good ☐ Reasonable ☐ Poor?

How did you find the training exercises ☑ Too challenging ☐ About right ☐ Too easy?

What were the strengths and weaknesses of the training?

Strengths → Perfect + Advanced Softwares
→ Enough + Relevant Informations
→ Lots of Exercises + Practical Works
→ Perfect + Well understand Speaker

Weaknesses → Venue was not good enough, that's why sometimes I felt sleepy because the Air Condition weren't well operated.

What areas of flood hydrology, river modelling and flood risk management do you think should we concentrate on during the next training and practical sessions in October 2006?

I need to know more on how to use the Softwares more effectively.

What other training in the fields of hydrology, river modelling and water resources management would assist you in carrying out your work more effectively?

Training on some of the Policies + Guidelines that will help me on make Flood Monitoring Policies. Also some GIS Trainings on Making perfect maps + models.

TRAINING EVALUATION FORM
Training in flood hydrology, river hydraulics and flood mapping

Was the general content of the training about what you had expected? ☑ Yes ☐ No

How do you think the training will help you carry out any work related to flood hydrology, river modelling and flood risk management in the future?

☑ Much more effectively ☐ Slightly more effectively ☐ The same as before

Did you rate the speakers as ☑ Good ☐ Reasonable ☐ Poor?

Were the presentations ☑ Too technical ☐ About right ☐ Not technical enough?

What was your overall assessment of the training ☑ Excellent ☐ Good ☐ Reasonable ☐ Poor?

What was your assessment of the training material ☐ Excellent ☑ Good ☐ Reasonable ☐ Poor?

How did you find the training exercises ☑ Too challenging ☐ About right ☐ Too easy?

What were the strengths and weaknesses of the training?

- Need more time, like 5-6 weeks for this kind of study
- Training is really challenging, bring some more skills about flood modelling, also new techniques such as computer software used

What areas of flood hydrology, river modelling and flood risk management do you think should we concentrate on during the next training and practical sessions in October 2006?

- Should put more focus on computer modelling techniques and skills.

What other training in the fields of hydrology, river modelling and water resources management would assist you in carrying out your work more effectively?

- River geomorphology.

TRAINING EVALUATION FORM
Training in flood hydrology, river hydraulics and flood mapping

Was the general content of the training about what you had expected? ☑ Yes ☐ No

How do you think the training will help you carry out any work related to flood hydrology, river modelling and flood risk management in the future?

☐ Much more effectively ☑ Slightly more effectively ☐ The same as before

Did you rate the speakers as ☐ Good ☑ Reasonable ☐ Poor?

Were the presentations ☐ Too technical ☑ About right ☐ Not technical enough?

What was your overall assessment of the training ☑ Excellent ☐ Good ☐ Reasonable ☐ Poor?

What was your assessment of the training material ☐ Excellent ☑ Good ☐ Reasonable ☐ Poor?

How did you find the training exercises ☑ Too challenging ☐ About right ☐ Too easy?

What were the strengths and weaknesses of the training?

Strengths
- working together of trainees
- time period for data collection
- number of trainees
- most of the training materials were understandable but few unfamiliar terms.
- number of exercises which improved some background

Weaknesses
- lack of field activity which might help other trainees

What areas of flood hydrology, river modelling and flood risk management do you think should we concentrate on during the next training and practical sessions in October 2006?

- Roughness
- at least a day for a field activity
- more practice with the RAS and HMS softwares

What other training in the fields of hydrology, river modelling and water resources management would assist you in carrying out your work more effectively?

- Personally, just want to know and learn both softwares to upgrade knowledge and give advisories to public

TRAINING EVALUATION FORM
Training in flood hydrology, river hydraulics and flood mapping

Was the general content of the training about what you had expected? ☒ Yes ☐ No

How do you think the training will help you carry out any work related to flood hydrology, river modelling and flood risk management in the future?

☐ Much more effectively ☐ Slightly more effectively ☐ The same as before

Did you rate the speakers as ☒ Good ☐ Reasonable ☐ Poor?

Were the presentations ☐ Too technical ☒ About right ☐ Not technical enough?

What was your overall assessment of the training ☒ Excellent ☐ Good ☐ Reasonable ☐ Poor?

What was your assessment of the training material ☒ Excellent ☐ Good ☐ Reasonable ☐ Poor?

How did you find the training exercises ☐ Too challenging ☐ About right ☐ Too easy?

What were the strengths and weaknesses of the training?

Logical progression from theory → practical ex.
Just need to link exercises back to theory
well defined objectives that were achievable.
It would be good if you could
at the end of session after the exercise incl.
a written test that would be a check of the
objectives.

What areas of flood hydrology, river modelling and flood risk management do you think should we concentrate on during the next training and practical sessions in October 2006?

flood hazard zone mapp. incl drainage works.
improvements/development on the upper & lower →
change flood hazard map. for ~~for~~
Risk - identifying zones. potential/possible mitigation
strategies. 2-D modelling / 3D.

What other training in the fields of hydrology, river modelling and water resources management would assist you in carrying out your work more effectively?

Incorporating HEC HMS → RAS → GIS.
hazard ~~as~~ risk maps.
What are the requirements to input models
into GIS?

Adaptation to other catchments.

No. for someone participants ongoing digitisation of old records

TRAINING EVALUATION FORM
Training in flood hydrology, river hydraulics and flood mapping

Was the general content of the training about what you had expected? ☐ Yes ☐ No

How do you think the training will help you carry out any work related to flood hydrology, river modelling and flood risk management in the future?

☑ Much more effectively ☐ Slightly more effectively ☐ The same as before

Did you rate the speakers as ☑ Good ☐ Reasonable ☐ Poor?

Were the presentations ☐ Too technical ☑ About right ☐ Not technical enough?

What was your overall assessment of the training ☑ Excellent ☐ Good ☐ Reasonable ☐ Poor?

What was your assessment of the training material ☑ Excellent ☐ Good ☐ Reasonable ☐ Poor?

How did you find the training exercises ☑ Too challenging ☐ About right ☐ Too easy?

What were the strengths and weaknesses of the training?

The strengths of the training is to concentrate and focus on flood hydrology, river hydraulics and flood mapping, is the application equations, softwares, designs and to learn how to reduce flood and safety for the communities.

The weaknesses of the training is not enough resources like computers, stationaries and durations of the training.

What areas of flood hydrology, river modelling and flood risk management do you think should we concentrate on during the next training and practical sessions in October 2006?

Both of them we should concentrate on during the next training.

What other training in the fields of hydrology, river modelling and water resources management would assist you in carrying out your work more effectively?

Flood risk management.

TRAINING EVALUATION FORM
Training in flood hydrology, river hydraulics and flood mapping

Was the general content of the training about what you had expected? (Yes) No

How do you think the training will help you carry out any work related to flood hydrology, river modelling and flood risk management in the future?

(Much more effectively) Slightly more effectively The same as before

Did you rate the speakers as (Good) Reasonable Poor?

Were the presentations Too technical About right Not technical enough? OK for starters

What was your overall assessment of the training (Excellent) Good Reasonable Poor?

What was your assessment of the training material (Excellent) Good Reasonable Poor?

How did you find the training exercises Too challenging About right Too easy?

What were the strengths and weaknesses of the training? It was a good challenge. Made us think a lot.

* Overall the training was an eye opener for me. I was able to learn more new stuff that would enhance my duties at work. The lecture material as well as the exercises, were well-prepared and easy to understand. The exercises were a good form of practice, putting the theory aspects to work.

* The only weakness I observed, was that the organisers had failed to identify b4 hand the datasets they needed from Samaras different working divisions, so we had to spend the 1st + 2nd weeks just running after data. In the future, we should already ask for the data in advance b4 the training happens.

What areas of flood hydrology, river modelling and flood risk management do you think should we concentrate on during the next training and practical sessions in October 2006?

Flood risk management

What other training in the fields of hydrology, river modelling and water resources management would assist you in carrying out your work more effectively?

None of all the above suggested fields would benefit me in carrying out my duties better.

APPENDIX D

Training Examination Questions

Appendix D Training Examination Questions

1) One of the most important input parameters for flood modelling is the flow. What are the different ways to assess a design flow (e.g. a 1 in 100 years flood) and what do you think would be the most appropriate way to assess the design flood flow for the Vaisigano River catchment draining to Apia?

2) What are the main components of a flood hydrograph?

3) What do you think is more important in generating flooding in Samoa - a long duration rain storm lasting several days or high rainfall intensities lasting for only a short period (e.g. 2 to 3 hours)?

4) What are the assumptions you make, if you model a uniform steady flow?

5) What data do you need to build a hydraulic model of the Vaisigano River?

6) What do you understand by the term roughness in the context of river modelling? What are its components and how can you assess it?

7) Why can you use a weir equation to transform water levels into flow?

8) How do you calibrate a hydraulic model of a river and why do you think this is important?

9) What are the main elements of uncertainty in hydraulic modelling of a river and how can you assess them?

10) What is a flood hazard and how do you define flood risk? How would you express the flood hazard of the Vaisigano River and the flood risks to Apia town on a map?

11) What are the different options for reducing flood risk to an urban area? Which do you consider to be the most appropriate for the Apia urban area?

12) What are the different methods by which flood maps can be produced?

APPENDIX E

Training Slides

Appendix E Training Slides

Day 1

Introduction to the training

Introductions

- Who are you?
- What do you hope to gain from the training and the project?
- What is your experience of flood hydrology and hydraulic modelling?

Course objectives

- To provide an overview of flood hydrology and river hydraulics
- To discuss issues related to estimating flood levels
- To provide illustrations from real life from the South Pacific
- To allow participants time to practise using the material

Format of course

- Presentations
- Exercises
- Discussion
- Documentation

Background to hydrology and hydraulics

- Definitions
- Hydrometric analysis
- Flood hydrology
- River flow processes
- Flow estimation
- Examples for practice

Rivers in the rural and built environment

- Conveyance
- Channel roughness
- Morphology
- Calculating water levels
- Structures and flood defences
- More examples and discussion
- Flood mapping

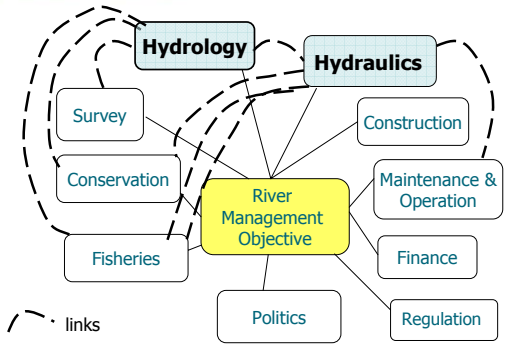
What will we learn?

- Knowledge of hydrometric data
- Construct a rating curve from data
- Different methods of estimating flood hydrographs
- Develop knowledge of open channel flow principles

What will we learn?

- Morphological river processes
- Know how water levels are calculated from flows
- What affects water levels at low and high flows
- Methods for assessing flood risk

River management



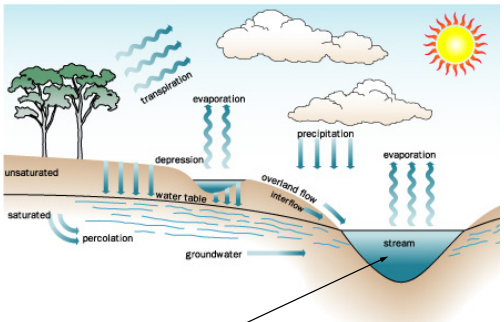
Training modules Day 1

- Processes and definitions
- Precipitation
- Rating curves
- Flood flow estimation using statistical methods
- Rainfall – runoff methods

Training modules Day 2

- Morning
- Introduction to HEC – HMS modelling
- Afternoon
- Field visit to demonstrate flow gauging

Training modules – how do they fit together?



Overall objective of Days 1 and 2 is to be able to estimate flood flows here

Training modules Day 3

Course to take place in one weeks time!

Concepts and principles in hydraulics

Introduction to river modelling

River resistance and roughness

Floodplain mapping

Training modules Day 4

Course to take place in one weeks time!

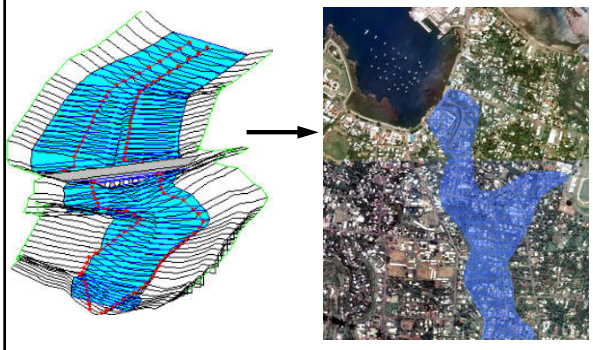
River morphology

Methods of flood defence

Risk uncertainty and error

Introduction to HEC-RAS modelling

Training modules – how do they fit together?



Processes and definitions

Learning objectives

To understand common process and definitions used in hydrological and hydraulic modelling

Runoff

Flow that enters the river system following precipitation (rainfall)

A key area of study in hydrology

Can be separated into two main components

- Fast/direct
- Slow

Sometimes expressed as a percentage

Stage

Stage is the water level measured above a datum, usually denoted by the symbol "h"

Measured in metres above a datum

Discharge

Discharge is the rate of volume of water flowing through a river section, usually denoted by the symbol "Q"

Measured in

- cubic metres per second or
- cumec or
- m^3/s

Mean flow velocity

Discharge divided by flow area

$$V = \frac{Q}{A}$$

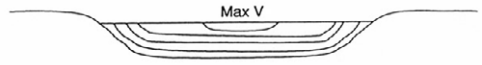
The velocity is at right angles to the cross-section, measured in units m/s

It is a typical value for the section

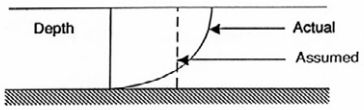
In flood conditions we may calculate average velocities in the channel and for the flood plains

Velocity distribution

Variation across a section

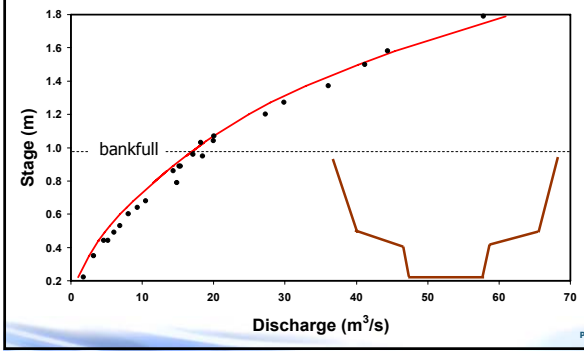


Variation with depth



A stage versus discharge rating curve

Plot of stage against discharge

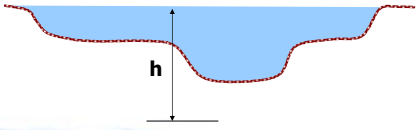


Conveyance "K"

A measure of the capacity of a river, Conveyance "K" depends on stage, h

$$Q = K(h)\, s^{0.5}$$

- **Q is discharge,**
- **s is water surface gradient**



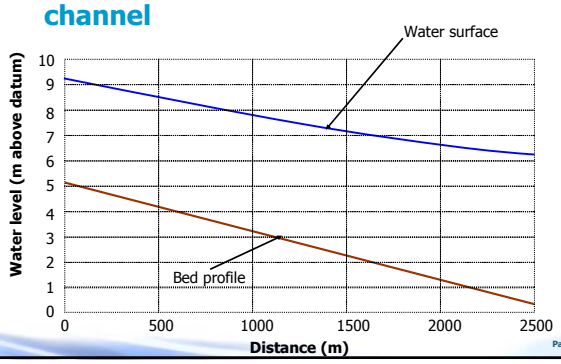
Backwater influence

The upstream effects of a "control" on water level e.g.

- **ponding behind a weir**
- **raised water level from constricting the flood plain**

Water surface profile

Plot of stage against distance along the channel

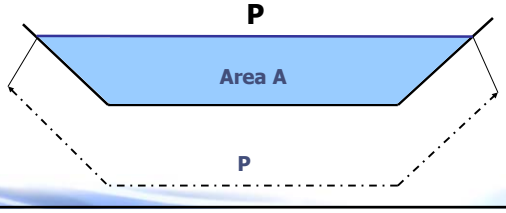


Hydraulic radius

Represents the shape of the cross section

Ratio of Area, A to Wetted Perimeter, P

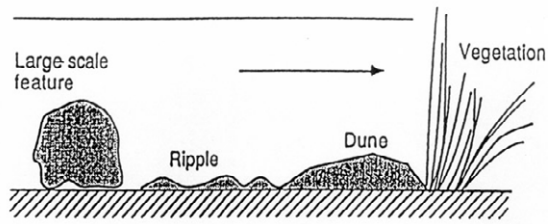
$$R = \frac{A}{P}$$



Flow resistance

The effect of the river bed and banks to slow down the water flow

Causes:



Sediment

Solid material transported by the flow

Trash

Floating debris carried by the flow

Probability and frequency

Probability

The chance that some event (e.g. a flood this year) might happen

Frequency

The rate of incidence of an event - especially from observations

Often data on frequency is used to estimate probability

Flood probability

Annual Probability, P

- The chance that the condition will be equalled or exceeded in any year
- Sometimes expressed as a percentage

Return Period, T

- The average interval in years between occurrences of the condition

Relationship

- $T = \frac{1}{P}$

Precipitation and runoff

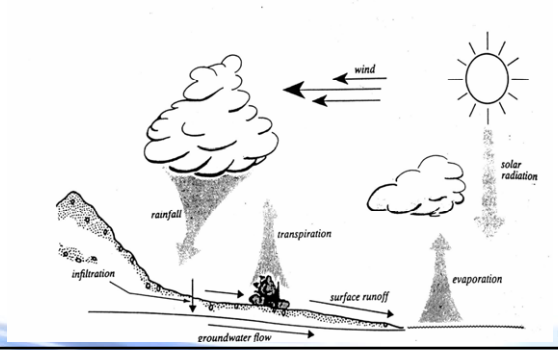
Learning objectives

- Understand different forms of precipitation
- Understand methods to estimate areal rainfall
- Understand rainfall intensity – frequency – duration curves
- Understand the runoff process

Skills acquired

- To estimate rainfall intensity from a rainfall – intensity –duration curves
- To calculate areal rainfall
- To estimate effective rainfall

The Hydrological Cycle



Precipitation

The term precipitation denotes all forms of water that reach the earth from the atmosphere. The usual forms are:

- **rainfall**
- **snowfall**
- **hail**
- **frost**
- **dew**

Rain approaching Samoa

Precipitation

The term rainfall is used to denote precipitation in the form of water drops of sizes larger than 0.5 mm. On the basis of its intensity rainfall is classified as

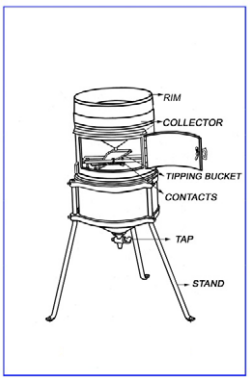
Type	Intensity
1. Light rain	Trace to 2.5 mm/hour
2. Moderate rain	2.5 to 7.5 mm/hour
3. Heavy rain	>7.5 mm/hour

Measurement of rainfall intensity

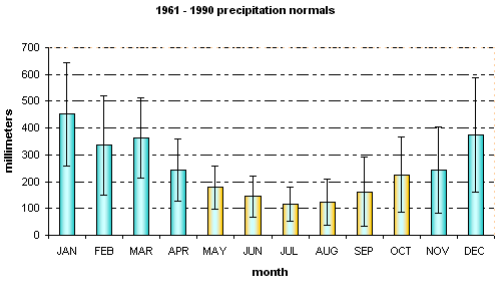
Methods by which rainfall intensity can be measured include:

- Tipping bucket rain gauge
- Weighing bucket type
- Natural siphon or float type gauge
- Radar

Tipping bucket rain gauge



Precipitation - Samoa



Mean annual rainfall is approximately 3000 mm

Rain gauge network

The area of the rain gauge is very small compared to the areal extent of the storm. To get a representative picture of a storm over a catchment the number of rain gauges should be as large as possible. Factors to consider with respect to the density of the rain gauge network

- **Costs**
- **Topography**
- **Accessibility**

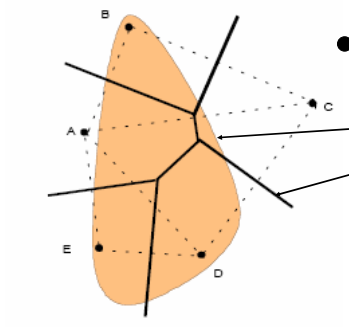
Estimating areal precipitation

Rain gauges represent only a point sampling of the areal distribution of a storm. For hydrological analysis a knowledge of the rainfall over the whole catchment is need. Methods that can be used include:

- **Calculating the arithmetic mean**
- **Thiessen's polygons**
- **Isohyetal method**
- **Radar**

HR Wallingford
Working with water

Thiessen's polygons

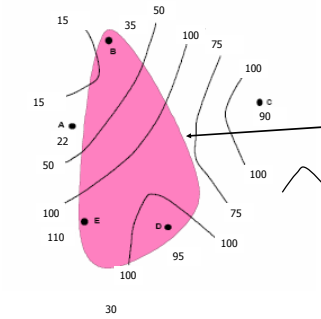


Rain gauge

Catchment area

Thiessen's polygons

Isohyetal method

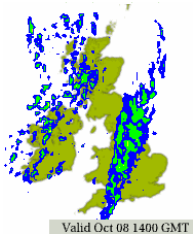


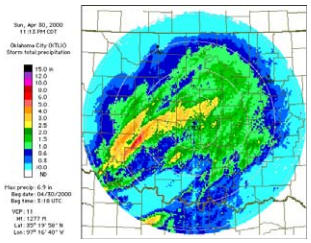
Rain gauge

Catchment area

Contour line of equal precipitation - isohyetal

Radar rainfall





Intensity – duration –frequency curves

The intensity of a storm decreases with the increase in storm duration. Further more a storm of any given duration will have a higher intensity if its return period is large. Rainfall intensity - duration – frequency curves are used for many design problems.

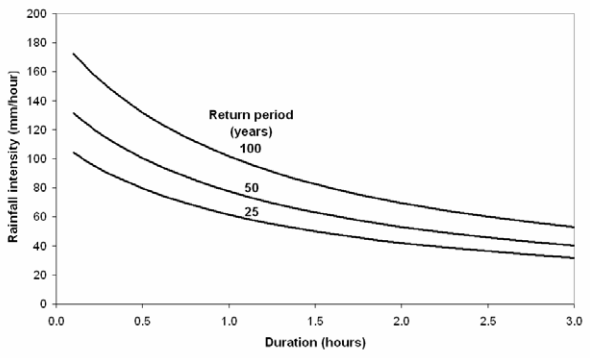
Intensity - frequency - duration

The relationship between rainfall intensity *i* (mm/hour), duration *D* (hours) and return period *T* is commonly expressed in the form:

$$i = \frac{K T^{x}}{(D + a)^{n}}$$

Where K, x, a and n are constants

Intensity - frequency - duration

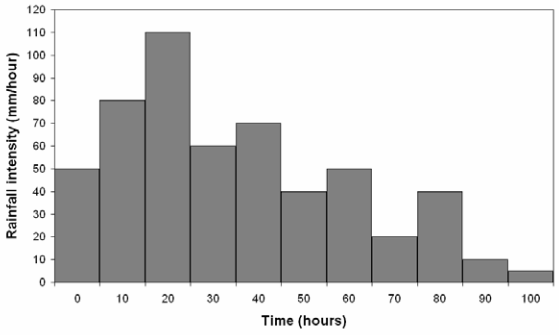


Hyetograph

A hyetograph is a plot of rainfall intensity against time interval. It is useful because:

- **It can be used in the development of design storms to predict large floods**
- **The area under the hyetograph represents the total precipitation in the period**
- **The time interval depends on the size of the catchment**

Hyetograph

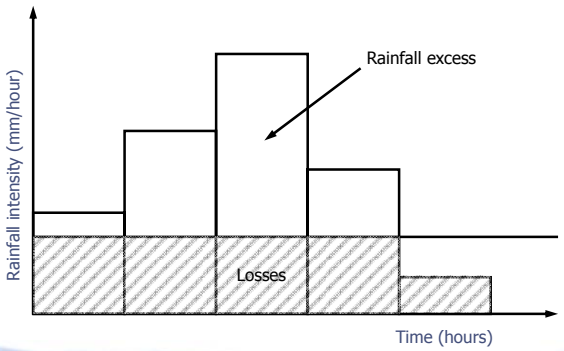


Effective rainfall

Effective or excess rainfall is that rainfall that is neither retained on the land surface nor infiltrated into the soil. The graph of effective rainfall versus time :

- **It can be used in the development of design storms to predict large floods**
- **The area under the hyetograph represents the total precipitation in the period**
- **The time interval depends on the size of the catchment**

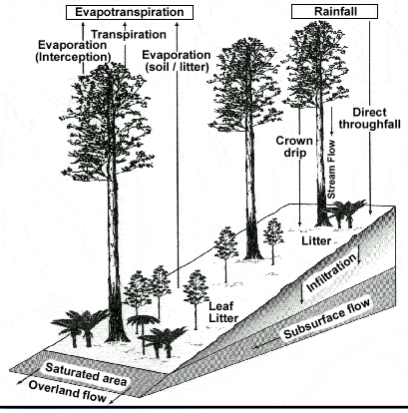
How to estimate effective rainfall



Runoff process

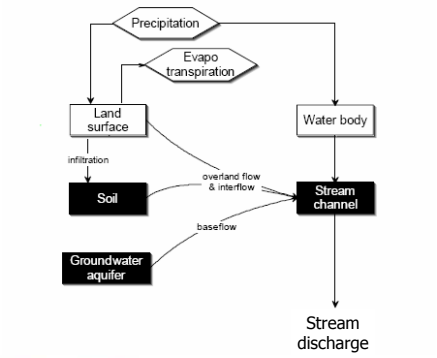
1. Usually water falling as precipitation returns to the atmosphere through evaporation and transpiration. However, during a storm event, this evaporation and transpiration is limited.
2. Depending upon the soil type, ground cover, antecedent moisture and other properties, a portion may infiltrate and move horizontally as interflow just beneath the surface, or percolate vertically to the groundwater aquifer beneath the catchment.
3. The interflow moves into the stream channel.
4. Water in the aquifer moves slowly, but eventually, some returns to the channels as baseflow.
5. Water that does not pond or infiltrate moves by overland flow to a stream channel.
6. The stream channel is the combination point for the overland flow, the precipitation that falls directly on water bodies in the catchment , and the interflow and baseflow

Runoff process



Runoff

Runoff process in HEC - HMS



Exercises

Precipitation and runoff exercises

Exercise 1

If a total rainfall amount of 100 mm falls over the Vasigano catchment and the initial loss and infiltration losses are estimated to be 27 mm what is the effective rainfall?

Exercise 2

The relationship between rainfall intensity *i* (mm/hour), duration *D* (hours) and return period *T* for Apia can be obtained by the equation:

$$i = \frac{110T^{0.5}}{(D+1)^{0.75}}$$

Exercise 2

Plot a rainfall intensity – duration – frequency curve for the 1 in 100 year return period. Use the graph paper and table provided.

Exercise 2

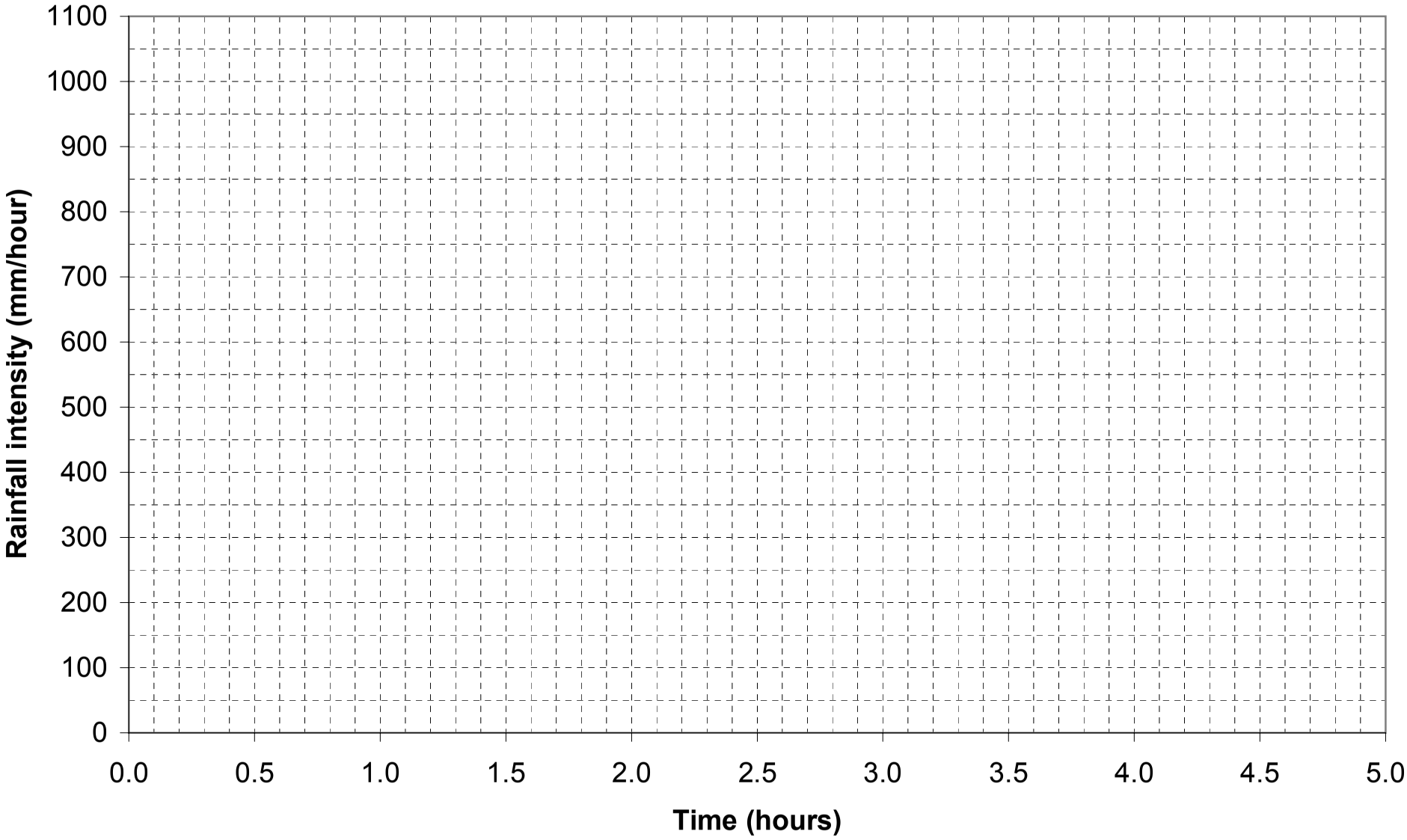
If the flow Q for a 5 km^2 catchment can be estimated from the equation

$Q = 0.005iA$

Where A is the catchment area and is the rainfall intensity. If the runoff takes 0.5 hours to reach the catchment outlet calculate the 1 in 100 year flow. Note use the 0.5 hour rainfall intensity – estimate this from your graph.

Duration (D) (hours)	**Rainfall intensity $i = 110T^{0.5}/(D+1)^{0.75}$ (mm/hour)**
0.1	
0.2	
0.4	
0.6	
0.8	
1.0	
2.0	
3.0	
5.0	

Note: T = 100


Rainfall intensity (mm/hour)
1100
1000
900
800
700
600
500
400
300
200
100
0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Time (hours)

Rating curves

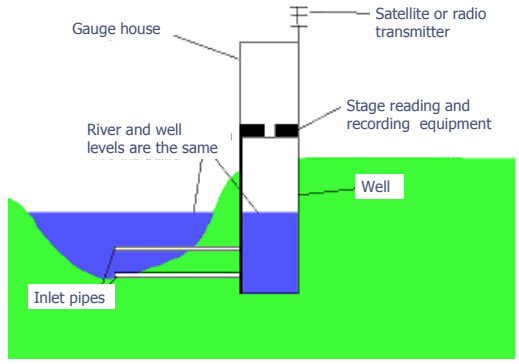
Learning objectives

- Understand factors that affect the shape of stage versus discharge curves
- Understand the practical difficulties of estimating flows from stage versus discharge curves
- Understand the uses of stage discharge curves

Skills acquired

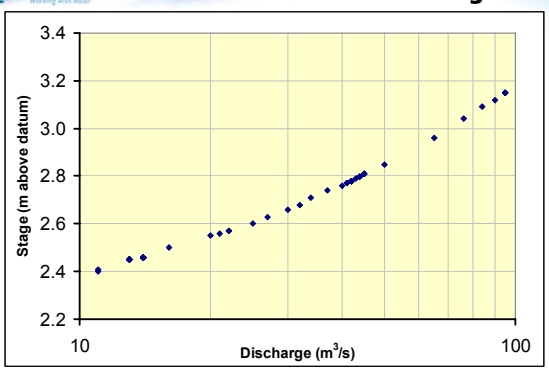
- To be able to plot a stage versus rating curve
- To be able to extrapolate a stage versus rating curve to estimate high flows

Flow gauging station



Flow gauging station

Rating curve



Rating curves
Derive information from data

- Relate river level or depth to discharge
- Unique or looped curves (where slope of river is less than 0.4 m/km)
- Allow data validation by checking latest measurements against earlier ones
- Care needed when there is a change of hydraulic condition (e.g. out-of-bank flow)
- Allows for extrapolation above the highest recorded flow

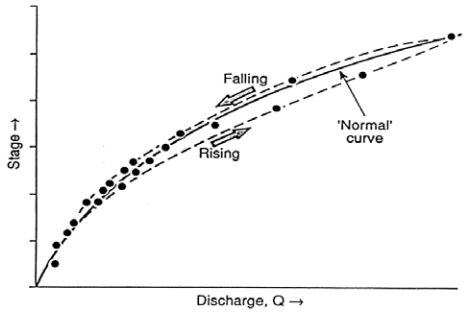
Rating curves
Typical rating equations

- General form of rating over a range of level

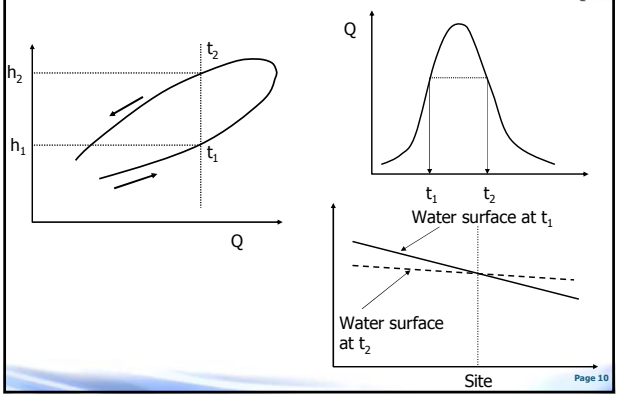
$$Q = a\,(h - b)^c$$

- Coefficient b represents a local datum
- Coefficient c has some theoretical values for structures and simple cross-sections
- Log - Log fitting by eye or with software
- Several equations, each for a range of level, or change in channel shape through time

Rating curves
Typical example:



Rating curves
Reason for loop



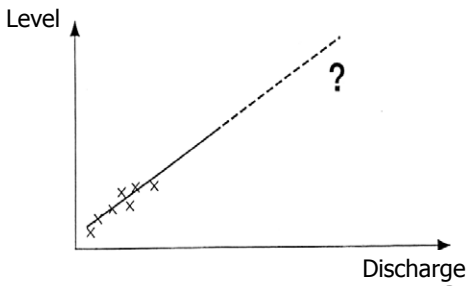
Rating curves
Adjustment for looped rating

- Adjust observations for rising or falling stage during measurement
- Measured discharge exceeds "normal" flow on rising flood stage
- Discharge is less than normal flow on falling flood stage
- Biggest impacts for rapidly varying, out-of-bank flows and wide flood plains

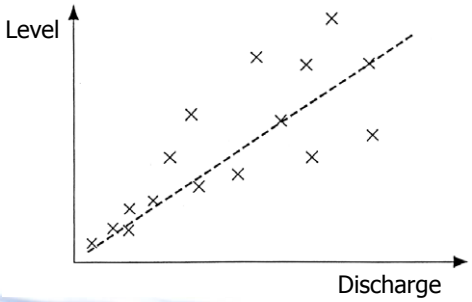
Rating curves
Practical difficulties

- Extrapolation above the highest gauging
- Backwater from a downstream control
- Bypass flow under flood conditions
- Out of bank section geometry
- Seasonal changes (growth and decay of vegetation)
- Morphological effects (mobile bed, alluvial friction)

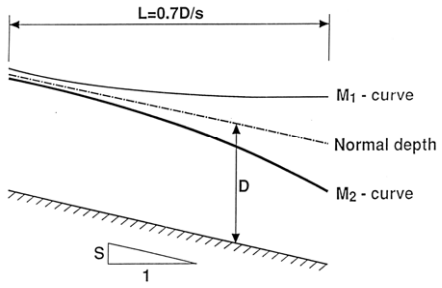
Rating curves
No data for high flows



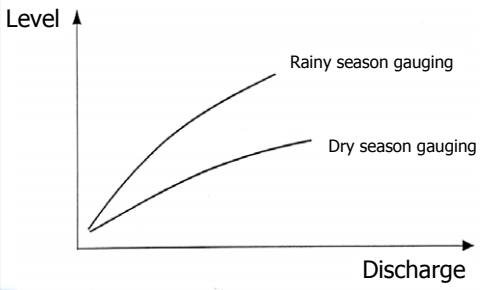
Rating curves
Backwater influence



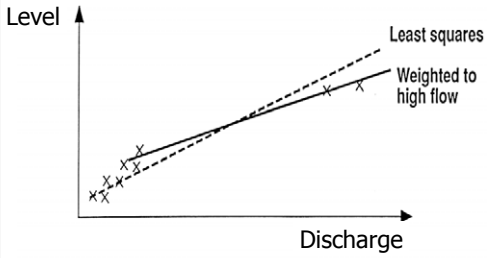
Rating curves
Backwater length



Rating curves
Seasonal influence



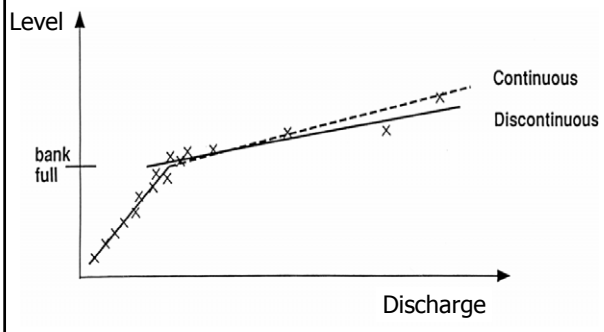
Rating curves
Fitting methods



Rating curves
Extension and fitting methods

- Use multiple equations
- Each has a defined range of stage
- Identify physically significant transitions
- Break point at bankfull stage ?
- Discontinuity at bankfull stage ?
- Analyse out-of-bank flow separately?

Rating curve extension
Out of bank fitting



Uses of hydrometric Data
Note this list is not exhaustive..

- Catchment water resources planning
- Flood forecasting
- Flood discharge estimation
- Flow frequency analysis
- Model calibration
- Design of river works and flood defences
- Regulation and consenting

Rating curve exercise

Exercise

The following data has been measured using a flow meter in Samoa

Stage (m)	Discharge (m^3/s)
2.41	11
2.46	14
2.5	16
2.55	20
2.63	27
2.66	30
2.68	32
2.71	34
2.74	37
2.76	40
2.79	43
2.81	45
2.85	50
2.96	65

Exercise

Plot the data on the graph paper provided. Note plot the discharge (Q) on the x axis and the stage (h) y axis

A curve of the following form has been fitted to the data:

$$Q = 0.0168(h - 0.0424)^{7.74}$$

Where Q is the flow and h is the stage

Plot this curve on the graph paper up to a stage (h) of 3.3 m

Use your graph to estimate the flow when the stage is 3.2 m

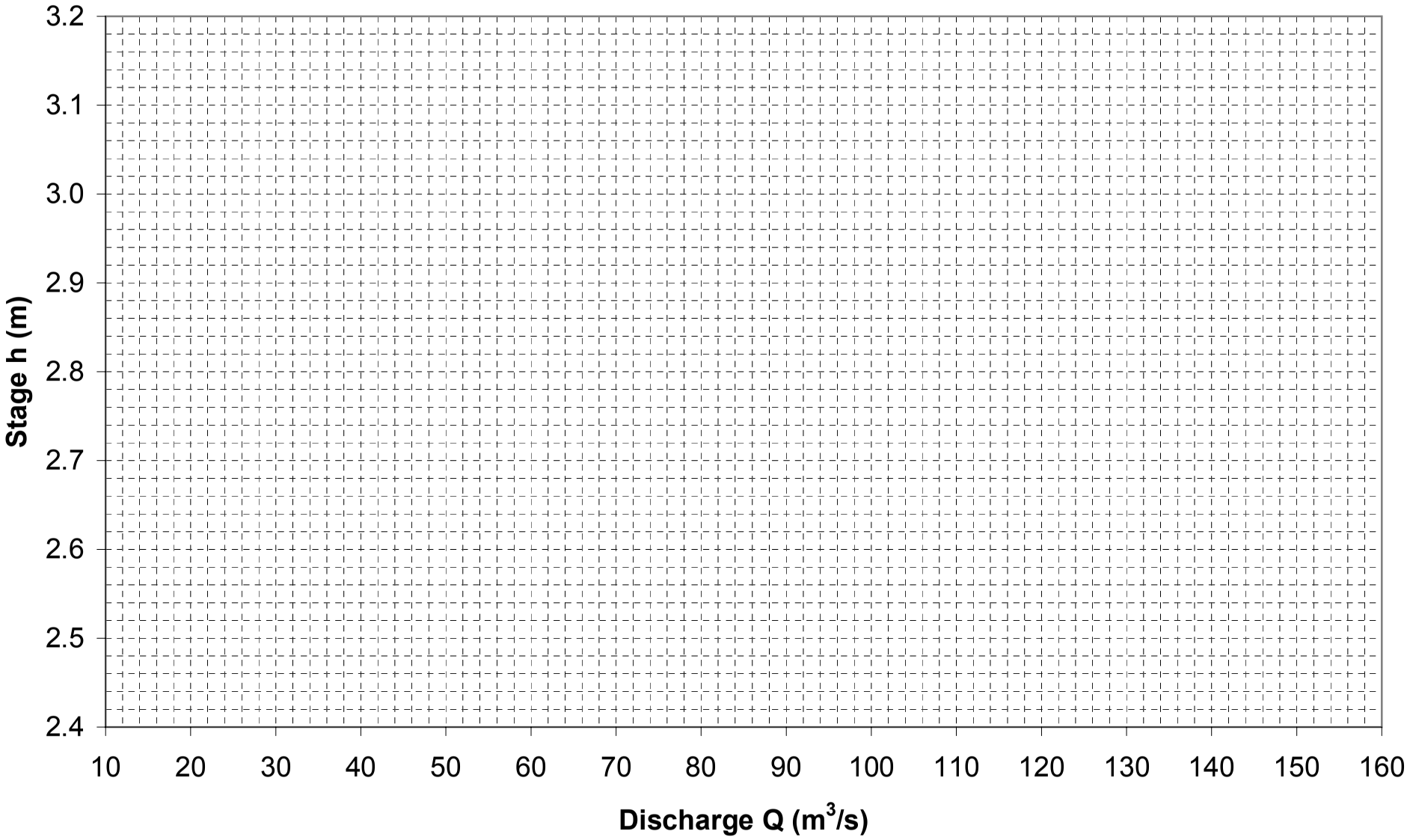
How accurate do you think your estimate of the flow at a stage of 3.2 m is?

Data for rating curve exercise

Stage (m)	Discharge (m^3/s)
2.41	11
2.46	14
2.50	16
2.55	20
2.63	27
2.66	30
2.68	32
2.71	34
2.74	37
2.76	40
2.79	43
2.81	45
2.85	50
2.96	65

Exercise sheet

Stage h (m)	Discharge (m^3/s) $Q = 0.0168(h - 0.0424)^{7.74}$
2.40	
2.50	
2.60	
2.70	
2.80	
2.90	
3.00	
3.10	
3.20	
3.30	


3.2
3.1
3.0
2.9
2.8
2.7
2.6
2.5
2.4
Stage h (m)
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
Discharge Q (m3/s)

Overview of flood flow estimation

Learning objectives

- Appreciate expected values of flood flows for the South Pacific
- Understand statistical methods to estimate the design flood
- Appreciate the uncertainty in estimating rare floods with limited data

Skills acquired

- To be able to estimate the 1 in 100 year return period using annual maximum flow data
- To be able to estimate the probability of a flood of given probability occurring within a certain period of time

Hydrological modelling

Nature of a flood producing system is complex interaction of:

- atmosphere
- land geology
- vegetation
- geomorphology
- soils
- activities of mankind

Therefore...

Modelling can only provide generalised estimates

Local information on observed floods is essential to "calibrate" models

Best information on future flood magnitudes is obtained from historical records (i.e. measured flood flows)

Typical maximum observed flood flows in the South Pacific

Country	Catchment area (km^2)	Maximum observed flood flow (m^3/s)	Discharge per unit area ($m^3/s/km^2$)
Molokai	12	762	63.5
Kauai	58	2470	42.6
Tahiti	78	2200	28.2
Fiji	104	6139	59.0
Fiji	128	996	7.8
Fiji	16	559	34.9
Fiji	80	447	5.6
American Samoa	2.6	14	5.4
Samoa	33	?	?

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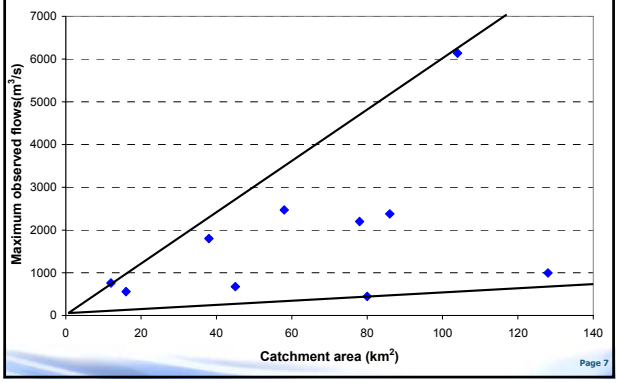
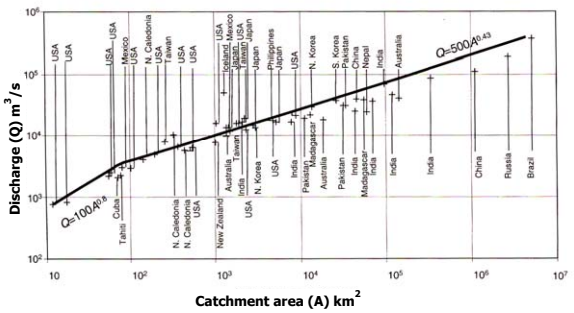
Typical maximum observed floods in the South Pacific



Page 7

Typical maximum observed floods in the world

Plot of discharge (Q) against catchment area (A) for the world's maximum floods



Page 8

Typical maximum observed floods in the South Pacific

For regions of the world, such as the South Pacific, that have intense rainfall a *very approximate* estimate of the maximum flood Q for a catchment with an area A can be estimated from:

$Q = 500A^{0.43}$ Where $A > 90$ km^2

$Q = 100A^{0.8}$ Where $A < 90$ km^2

Page 9

Flooding in Fiji

Page 10

Flood definitions

Design flood

The flood adopted for the design of a structure (e.g. bridge, culvert, flood wall)

Probable maximum flood (PMF)

The extreme flood that is physically possible as a result of the most severe combination of meteorological and hydrological factors.

Page 11

Estimating flood flows

Estimates of peak flood flows (magnitude)

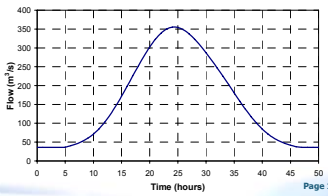
↓

Statistics — e.g. peak flow measured during a flood event often from a gauging station

Prediction of timing, shape and volume (hydrograph)

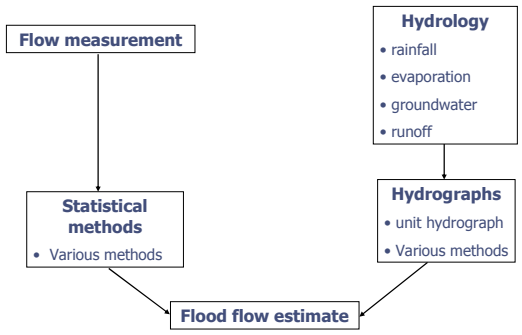
↓

Hydrological rainfall-runoff modelling



Page 12

Hydrology and flood flow estimation



Page 13

STATISTICAL METHODS

Return period

The return period, T, is the average interval (in years) between years containing a flood exceeding a given magnitude

The flood with return period T is referred to as the T year flood

The probability, P, of a T year flood happening in any one year is (1/T)

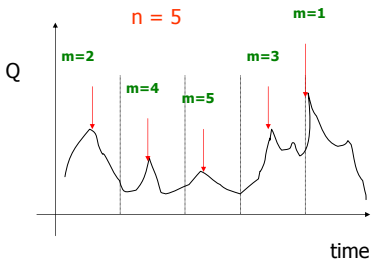
Page 15

Statistical analysis of data (1)

Produces flood estimates based on recorded historical pattern of runoff events

1) Select 'annual maximum' floods from the period of record
   - Ensure 'independence'
   - Use 'water' years
2) List events in descending order, and give rank, 'm'
3) Count total number of events in series = 'n'

Statistical analysis of data (2)



Statistical analysis (3)

Probability 'P' associated with each event can be computed from a number of formulae

e.g. $P = \frac{m}{n+1}$ or $P = \frac{m-0.44}{n+12}$

To predict flows for any return period, need a graph

However, plotted on graph paper, P against Q is unlikely to follow a straight line.

Several theoretical distributions have been proposed e.g. Gumbel, Generalised Logistic, Log Pearson

Statistical analysis (4)

Rank m	Flood flow (m^3/s)	Annual probability $P = \frac{m}{(n+1)}$	Return period T (years)
1	160	0.0196	51
2	135	0.0392	26
3	116	0.0588	17
⋮	⋮	⋮	⋮
50	21	0.980	1

Statistical analysis (5)

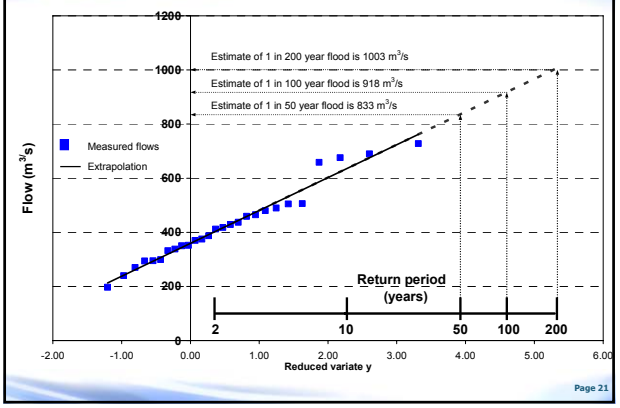
If, instead of plotting 'P' against Q, you plot the 'reduced variate' 'y' against Q

where $y = -\ln(\ln)(T/(T-1))$

Then (for Gumbel), the points should be a straight line

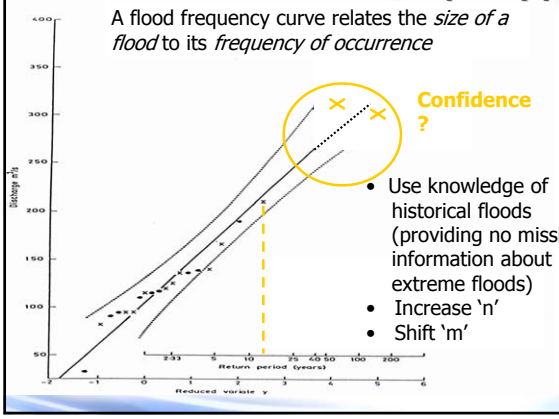
Extrapolate line to predict design floods

Statistical analysis (6)



Flood frequency plot

A flood frequency curve relates the *size of a flood* to its *frequency of occurrence*



- Use knowledge of historical floods (providing no missing information about extreme floods)
- Increase 'n'
- Shift 'm'

Some useful y values

Return period T (years)	Reduced variate y
T = 1000 years	y = 6.91
T = 100 years	y = 4.60
T = 50 years	y = 3.90
T = 25 years	y = 3.20
T = 10 years	y = 2.25
T = 5 years	y = 1.50

Sources of uncertainty

Choice of statistical distribution, fitting procedure etc

Duration of records normally so short that it is difficult to extrapolate with confidence

Flow series may not be 'homogeneous', e.g.

- **Change in data collection method, position, datum**
- **Land use change in the catchment (e.g. development)**
- **Climate change**

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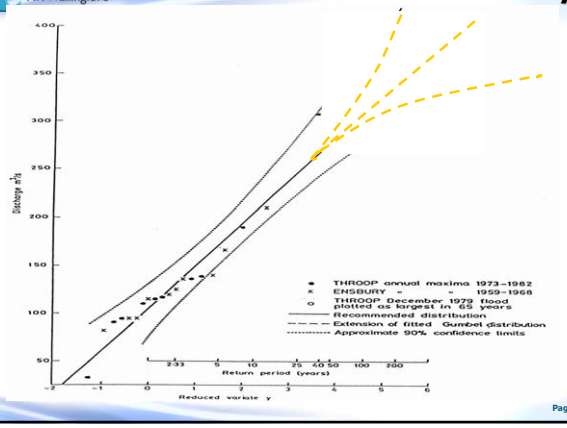
Sources of uncertainty


THROOP annual maxima 1973–1982
ENSBURY – – 1959–1968
THROOP December 1979 flood plotted as largest in 65 years
Recommended distribution
Extension of fitted Gumbel distribution
Approximate 90% confidence limits
Return period (years)
Reduced variate y

Regional flood frequency analysis

- Regional analysis adopted when data is limited
- Use flood flows from a "hydrologically homogenous region" to understand the relationship between the mean annual flood Q_{MAF} and the flood with a return period T, Q_T
- May be possible to use data from Fiji, American Samoa and Samoa to produce a regional flood frequency curve for ungauged catchments in Samoa?

Limitations of statistical methods

- The results of the statistical flood frequency analysis is dependent on the amount of data available
- The more data that is available the better!
- The there is a high degree of uncertainty in extrapolating to high return periods with limited data

Probability of a flood occurring in the next T years

The probability R of a flood with a return period of T years occurring in the next n years is given by the equation

$$R = 1 - (1 - \frac{1}{T})^n$$

Exercises

Exercise

Estimation of a 1 in 100 year flood flow

The problem

The following annual maximum flow data has been recorded at a flow gauging station draining a catchment with an area of 35 km² in Samoa over the past 16 years.

Year	Annual maximum flow (m^3/s)
1990/1991	42.0
1991/1992	18.5
1992/1993	5.0
1993/1994	61.0
1994/1995	18.0
1995/1996	11.0
1996/1997	15.0
1997/1998	19.0
1998/1999	7.0
1999/2000	9.0
2000/2001	100.0
2001/2002	10.0
2002/2003	6.0
2003/2004	4.0
2004/2005	45.0
2005/2006	17.5

The problem

The problem is to estimate the 1 in 100 year return period flood flow for the gauge using the two pieces of graph paper provided as follows:

(i) Rank the flows in descending order starting with the highest and finishing with the lowest.

(ii) Give a ranking number (m) to each flood flow. The largest flow will be ranked 1 and the smallest ranked 16.

(iii) Estimate the return period (T) of each flood flow using the equation T = (n+1)/m. (Note in this case n = 16).

(iv) Plot the flood flows on graph paper 1. Plot flood flows on the y axis and return period in years on the x axis.

The problem (continued)

(v) Draw a straight line through the points and estimate the 1 in 100 year flood flow from the graph.

(vi) Plot the flood flows on graph paper 2. Flood flows on the y axis and return period in years on the x axis.

(vii) Draw a straight line through the points and estimate the 1 in 100 year flood flow from the graph.

(viii) What is the difference between your two estimates of the 1 in 100 year flow using the different types of graph paper?

The problem (continued)

(ix) Which estimate do you think is correct?

(x) The equation below gives an estimate of the maximum flood (Q) flow for a catchment with an area of A km^2. What is the maximum flood that could be generated by the catchment?

$$Q = 100A^{0.8}$$

(xi) How does this compare with your 1 in 100 flood flow estimates?

1 in 100 year flood flow estimation

Flood flow (m^3/s)	Rank m	Return period T (years) T = (n+1)/m

Data for flood estimation exercise

Year	Annual maximum flow (m^3/s)
1990/1991	42.0
1991/1992	18.5
1992/1993	5.0
1993/1994	61.0
1994/1995	18.0
1995/1996	11.0
1996/1997	15.0
1997/1998	19.0
1998/1999	7.0
1999/2000	9.0
2000/2001	100.0
2001/2002	10.0
2002/2003	6.0
2003/2004	4.0
2004/2005	45.0
2005/2006	17.5

Worksheet flood estimation

Flood flow (m^3/s)	Rank m	Return period T (years) T = (n+1)/m

Exercise

Occurrence of flooding within a certain time period

The problem

A bridge has an expected design life (n) of 25 years and is designed to pass a flood with a design return period (T) of 1 in 100 years without being overtopped.

(i) What is the probability (R) of the bridge being overtopped during its 25 year design life (n)?

(ii) If the designer only wants a 10% chance (R) of the bridge being overtopped during its 25 year design life (n) what flood return period (T) should the bridge be designed to pass?

The equation

Use the equation:

$$R = 1 - \left(1 - \frac{1}{T}\right)^n$$

Where:

T is the return period of the design flood
n is the design life of the bridge
R is the probability of a T year flood occurring during n years

The world's maximum floods

It is not appropriate in a catalogue of this nature to attempt a systematic analysis of the published data nor to propose avenues of research that might be developed from the data. It is appropriate, however, to define some index which permits an assessment of whether one flood is larger than another that was perhaps observed on a different river. In this respect the Francou index, k, (Francou & Rodier, 1967) used in the first edition, has been used again in this edition. It is given by:

$$k = 10\ ([1 - [\log(Q) - 6] / [\log(A) - 8]])$$

where Q is the largest flood in $m^3\ s^{-1}$ and A is the catchment area in km^2.

Fifty-four floods, with k values greater than 5 were selected (from a total of some 1500 floods in the Catalogue). These are given in the Table and are plotted logarithmically in the Figure below giving an envelope curve with the following relations:

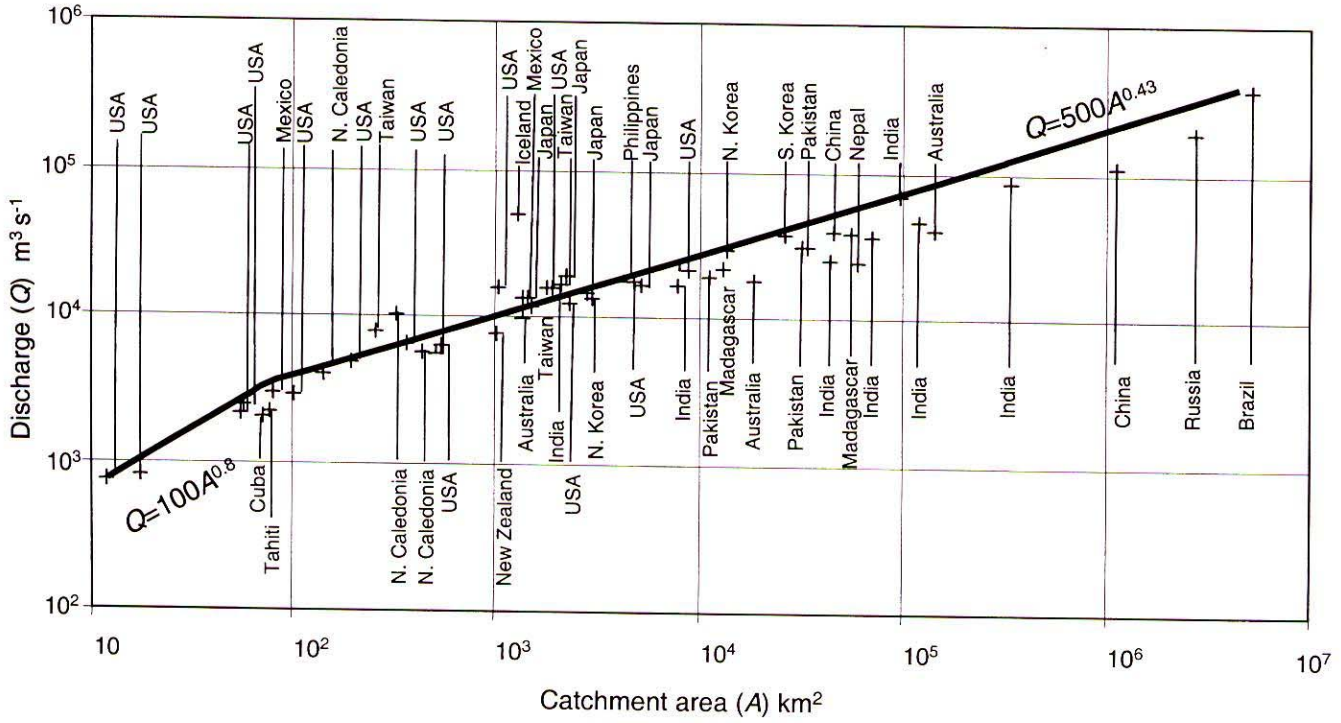
$Q = 500\ A^{0.43}$ for values of A greater than 90 km^2, and

$Q = 100\ A^{0.8}$ for values of A less than 90 km^2.

It is apparent that the straight line envelope curve above 90 km^2 has a k value of approximately 6 with some points lying above the line and some below it. The straight line below 90 km^2 has a k value of approximately 5.6 with some departures from this value.

It will be noted that there are no European countries on the envelope curve; most floods in Europe have k values between 3 and 5.

Plot of discharge (Q) against catchment area (A) for the world's maximum floods.



Country	Station	Catchment area (km^2)	Max. discharge ($m^3 s^{-1}$)	Year	k
USA, Hawai	Halawa	12.0	762	1965	5.49
USA, Puerto Rico	Las Piedras	17.7	816	1960	5.43
USA, Nevada	Nelson Landing, El Dorado Canyon	56.5	2150	1974	5.73
USA, Hawai	Wailua Lihue	58	2470	1963	5.82
Cuba	Buey San Miguel	73	2060	1963	5.62
French Polynesia, Tahiti	Papenoo	78	2200	1983	5.65
Mexico	San Bartolo	81	3000	1976	5.86
USA, Texas	North Fork, Hubbard Brook	102	2920	1976	5.77
New Caledonia	Quateme Embouchure	143	4000	1975	5.85
USA, Texas	Mail Trail Creek, Loma Alta	195	4800	1948	5.94
China, Taiwan	Cho Shui	259	7780	1979	6.22
New Caledonia	Quateme, Derniers Rapids	330	10400	1981	6.39
USA, Texas	Seco Creek d'Hanis	368	6500	1935	5.98
New Caledonia	Yate	435	5700	1981	5.81
Puerto Rico (USA)	Central Cambalache	518	5520	1899	5.73
USA, Nebraska	Little Nemaha, Syracuse	549	6 370	1950	5.83
New Zealand	Haast, Roaring Billy	1 020	7 690	1979	5.77
USA, Texas	Kickapoo Springs	1 040	16 000	1935	6.40
Iceland	Skeidara at Bru	1 300	50 000	1996	7.34
Mexico	Cithuatian, Paso del Mojo	1 370	13 500	1959	6.16
Australia	Pioneer at Pleystowe	1 375	9 840	1918	5.84
Japan	Nyodo Ino	1 463	13 510	1963	6.11
Taiwan	Hualien Bridge	1 506	11 900	1973	6.01
USA, Texas	W. Nueces, Bracketville	1 800	15 600	1935	6.20
India	Macchu	1 900	15 600	1979	6.06
Taiwan	Tam Shui, Taipei Bridge	2 110	16 700	1963	6.20
Japan	Shingu Oga	2 251	19 025	1959	6.29
USA, Texas	Pedernaies, Johnson City	2 330	12 500	1952	5.87
Japan	Yoshino Iwazu	2 810	14 470	1974	5.84
N. Korea	Daeryong Gang	3 020	13 500	1975	5.83
Philippines	Cagayan Echague Isabella	4 244	17 550	1959	5.98
USA, Texas	Nueces Uvalde	4 820	17 400	1935	5.87
Japan	Tone Yattajima	5 150	16 900	1947	5.87
India	Vsundhra at Kashinagar	7 820	16 790	1980	5.68
USA, California	Eel Scotia	8 060	21 300	1964	5.92
Pakistan	Ravi at Jassar	10 000	19 244	1955	5.71
Madagascar	Betsiboka	11 800	22 000	1927	5.78
North Korea	Toedong Gang	12 175	29 000	1967	6.06
Australia	Clarence at Lilydale	16 690	18 300	1954	5.40
South Korea	Han Koan	23 880	37 000	1925	6.05
Pakistan	Chenab at Marala	28 000	31 130	1957	5.76
Pakistan	Jhelum at Mangla	31 000	30 847	1992	5.70
India	Indravathi at Pathaguddem	40 000	24 862	1990	5.44
China	Hanjiang at Ankang	41 400	40 000	1583	5.87
Madagascar	Mangoky at Banyan	50 000	38 000	1933	5.70
Nepal	Sapta Kashi at Chatara Kothi	54 100	24 000	1980	5.04
India	Tapi at Kathur	64 000	36 500	1970	5.50
India	Narmada at Gurdeshwar	87 892	69 400	1970	6.21
India	Pranhita at Tekra	108 780	47 000	1986	5.52
Australia	Burdekin at Clare	129 660	40 400	1946	5.17
India	Godavari at Polaeshwaram	307 800	87 250	1907	5.78
China	Chang Jiang at Yitchang	1 010 000	110 000	1870	5.20
Russia	Lena at Kusur	2 430 000	189 000	1967	5.52
Brazil	Amazon at Obidos	4 640 000	370 000	1953	6.76

Francou, J. & Rodier, J. (1967) Essai de classification des crues maximales observées dans le monde. *Cahiers ORSTOM, serie Hydrologie* **IV**(3), 19–46. ORSTOM, Bondy, France.

Rainfall – runoff methods

Learning objectives

Understand why it is necessary to construct a hydrograph

Understand the effects of different catchment characteristics on the hydrograph shape

Understand the rainfall – runoff process to derive hydrographs

Skills acquired

To be able to understand the various components of a flood hydrograph

To be able to know what shape a hydrograph is likely to be based on the type of catchment

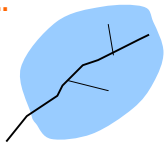
Why construct a flood hydrograph?

- Estimate timing of flood
- Calculate flood volume
- Estimating flood warning times
- Assessing the affect of land use change
- Assessing the effect of flood mitigation measures

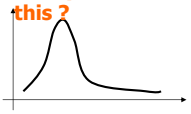
Rainfall - runoff method

When shape and timing of flood hydrograph is to be determined

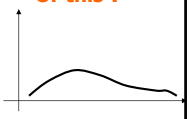
Does this ....



Give you this ?

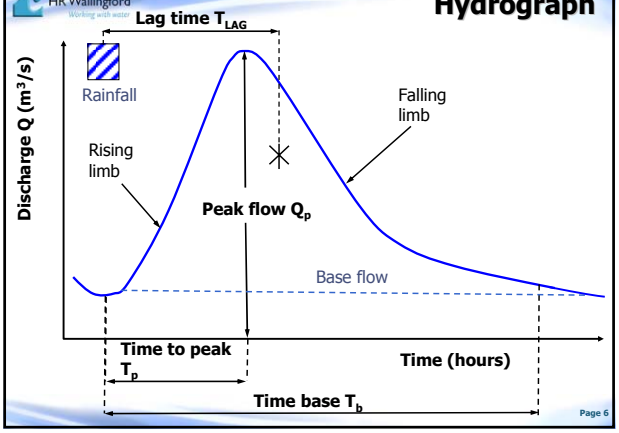


Or this ?



Technique for relating the runoff to the rainfall that caused it is the Unit Hydrograph Method

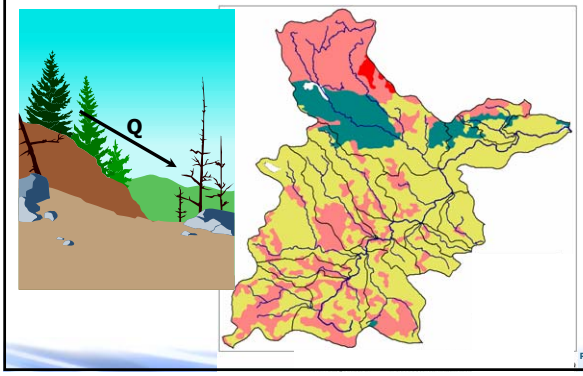
Hydrograph



Factors affecting flood hydrograph?

- Shape of the catchment
  - This affects the time water takes to reach the outlet
- Size of the catchment in terms of area A
  - Size of the flood is often related to A^n
- Slope of the channel
- Drainage density
  - Higher the drainage density the shorter the time to peak
- Land use
- Climatic factors

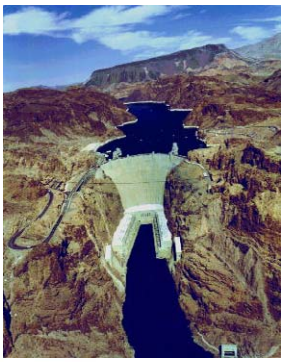
Catchment size, slope, soil type



Degree of urbanisation

Catchment wetness

Attenuation from lakes and reservoirs



What do you expect the characteristics of a flood hydrograph for the Vasigano catchment to be like?

Unit hydrograph (UH) theory

Unit hydrograph (UH) is the rapid response of the catchment to unit depth of effective rainfall falling in unit time

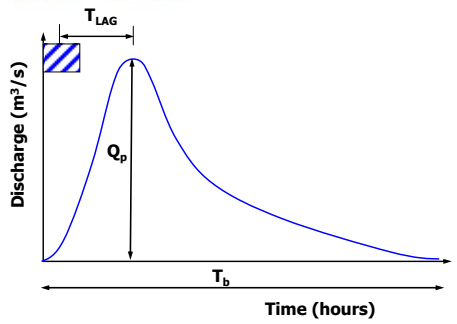
The concept makes three main assumptions:

- **Time invariance (unique and constant rainfall-runoff relationship)**
- **Linearity (increase in rainfall causes proportional increase in runoff)**
- **Superposition (total runoff is sum of individual runoff hydrographs)**

Hydrograph computation

1) Construct unit hydrograph

Unit hydrograph



Estimating Tp

From empirical equations

$Tp = C(L/S^{0.5})^n$

Where: C and n are constants related to the catchment

S is the slope of the river

L is the distance the water has to travel

From observed values of 'lag' time between centroid of rainfall and flow peak

Hydrograph computation

1) Construct unit hydrograph

2) Estimate percentage runoff

Percentage runoff

Percentage runoff is the proportion of the total rainfall input which shows up as rapid response runoff in the river.

It is estimated from:

Empirical equations e.g. US Soil Conservation Service Curve Number Method

Observed values if these are available

Hydrograph computation

1) Construct unit hydrograph

2) Estimate percentage runoff

3) Calculate design storm event rainfall

4) Distribute according to chosen profile

Design storm event

Design storm duration, D

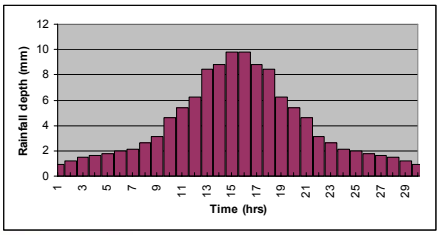
Design storm depth, P

Design storm profile

Design storm event

Estimate the critical storm duration in hours

Storm Depth is taken from the design rainfall



Hydrograph computation

1) Construct unit hydrograph

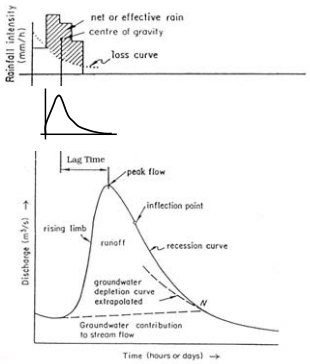
2) Estimate percentage runoff

3) Calculate event rainfall

4) Distribute according to chosen profile

5) Convolute net rain and UH

Rainfall-runoff approach



Net Rainfall

X

Unit Hydrograph

↓

Runoff Hydrograph

Hydrograph computation

1) Construct unit hydrograph

2) Estimate percentage runoff

3) Calculate event rainfall

4) Distribute according to chosen profile

5) Convolute net rain and UH

6) Add baseflow

Baseflow

Baseflow represents the flow in the river prior to the event

To estimate:

- From empirical equations
- From flood event analysis (records of rainfall and runoff)

Hydrograph computation

1) Construct unit hydrograph
2) Estimate percentage runoff
3) Calculate event rainfall
4) Distribute according to chosen profile
5) Convolute net rain and UH
6) Add baseflow

Problem catchments

Small (< 0.5 km^2)

Large (> 500 km^2)

Permeable catchments e.g. chalk

Urbanised catchments

Flat and low-lying, possibly with pumped drainage

Diversions/extensive channel works

HEC HMS

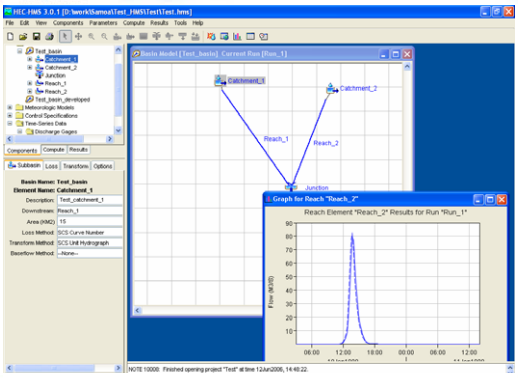
HEC HMS is a hydrological modelling system that includes a variety of models to produce flood hydrographs

User specified unit hydrograph

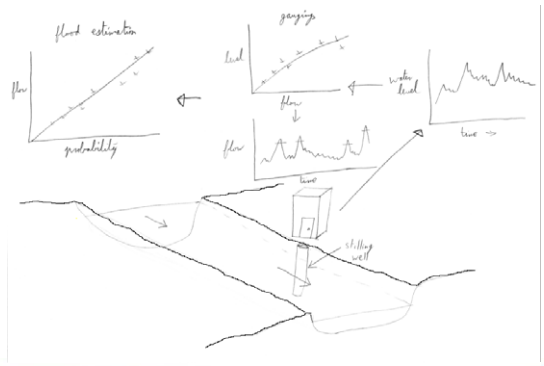
Clark's unit hydrograph

Soil Conservation Service unit hydrograph

HEC HMS



Summary of hydrology lectures



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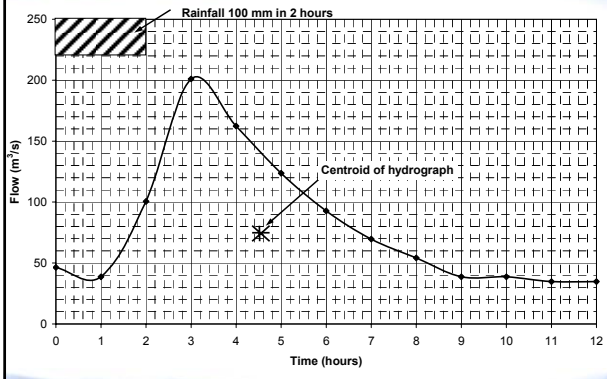
Rainfall – runoff exercise

Exercise



Page 2

Exercise

From the graph of the flood hydrograph estimate the following:

(i) The peak flood flow in m^3/s

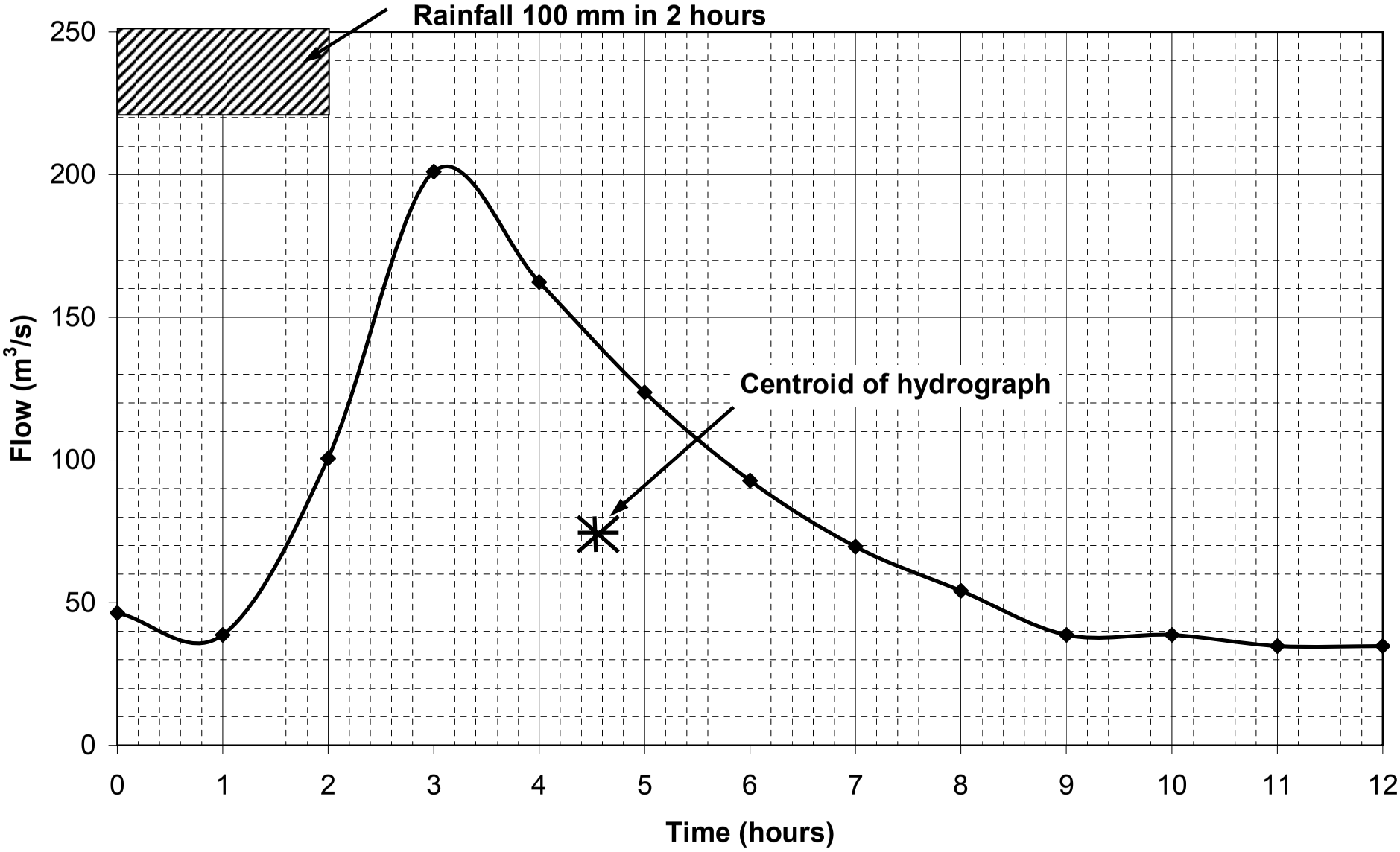
(ii) The time to peak in hours

(iii) The time base in hours

(iv) The base flow in m^3/s

(v) The lag time in hours

Page 3


Rainfall 100 mm in 2 hours
Centroid of hydrograph
Flow (m3/s)
Time (hours)
0
50
100
150
200
250
0
1
2
3
4
5
6
7
8
9
10
11
12

Day 2

An introduction to HEC HMS

Learning objectives

- Understand the components of HEC-HMS software
- Understand the different parts of the HEC HMS software interface
- Understand how to develop a HEC HMS project

Skills acquired and reasons for using HEC HMS

- To know the functionality of the HEC HMS software
- To appreciate how to develop a flood hydrograph using HEC HMS

Background to HEC HMS

HEC-HMS = Hydrologic Engineering Center's Hydrologic Modeling System

Developed by the US Army Corps of Engineers over a number of years

Latest version is 3.0.1

Available for free from the internet (www.hec.usace.army.mil) together with comprehensive manuals and references

What does HEC-HMS do?

HEC-HMS is designed to simulate the precipitation – runoff processes of catchments (known as watersheds in HEC-HMS)

It is designed to be applicable to a wide range of geographical areas and also to solve a wide range of problems

Uses of HEC-HMS

Flood hydrology

Water resources problems (e.g. water availability)

Effects of urbanisation on catchments

Flood forecasting

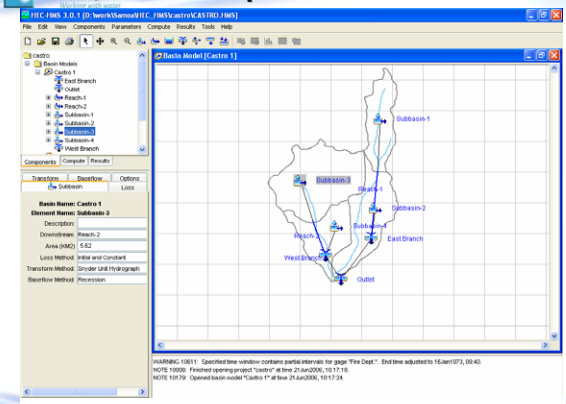
Design of dam spillways

Floodplain regulation

Components of HEC-HMS models

- **Basin model**
- **Meteorologic models – provides input to the basin model**
- **Control specifications – defines the time step and time period of a model run**
- **Input data – e.g. rainfall data**

Components of HEC-HMS models



Hydrologic elements of HEC-HMS

- **Subbasin – used to represent the physical catchment**
- **Reach – used to convey downstream**
- **Junction – used to combine flow from different hydrologic elements**

Hydrologic elements of HEC-HMS

Source – used to introduce flow into the model

Sink – used to represent the outlet of a catchment

Reservoir – used to model the attenuation of a hydrograph caused by a reservoir or storage area

Diversion – used to flow leaving the main channel

Subbasin and reach calculation methods

Subbbasin

– Runoff volume

– Direct runoff using unit hydrograph techniques

– Baseflow

Reach

– Routing methods including Muskingum, Muskingum-Cunge, Lag

Meteorologic model and control specifications component

The meteorologic model component – estimates the precipitation required by the subbasin element. It can use various types of precipitation data e.g gridded from radar, gauges etc

Control specifications component – Sets the time span of the model run. It includes a starting date and time, an ending date and time and a computation step

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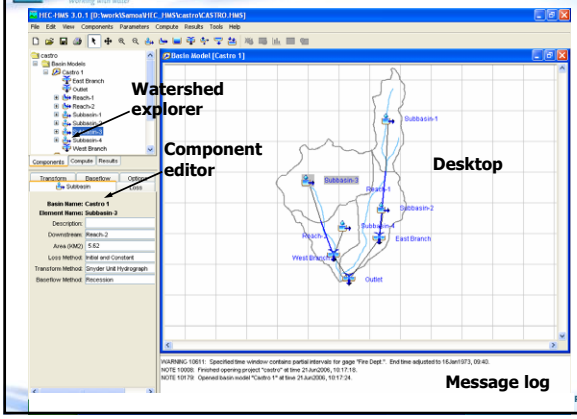
User interface



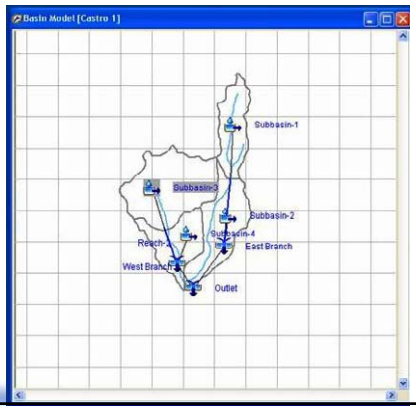
Watershed explorer

Component editor

Message log

```
WARNING 10611:  Specified time window contains partial intervals for gage "Fire Dept.".  End time adjusted to 16Jan1973, 09:40.
NOTE 10008:  Finished opening project "castro" at time 21Jun2006, 10:17:18.
NOTE 10179:  Opened basin model "Castro 1" at time 21Jun2006, 10:17:24.
```


Desktop



Developing an HMS model

- Create a new project.
- Input data needed by the basin and/or the meteorologic model
- Define the physical characteristics of the catchment by editing the basin model
- Select a method for calculating subbasin precipitation

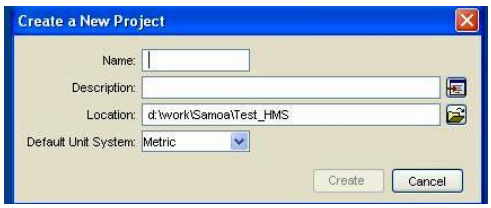
Developing an HMS model

Define the control specifications

Combine a basin model, meteorologic model and control specifications to create a simulation

View the results and modify the basin model, meteorologic model or control specifications as needed.

Creating a new project



Input data manager

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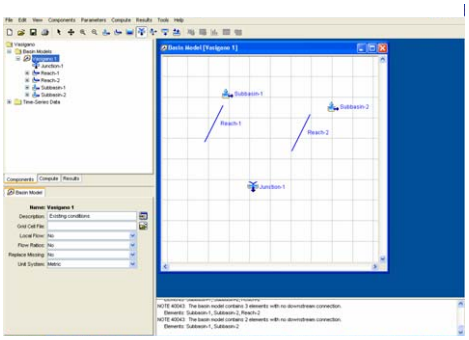
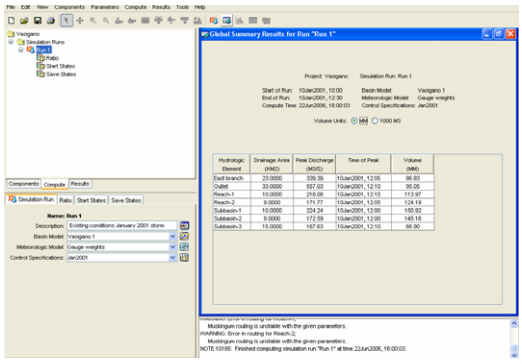
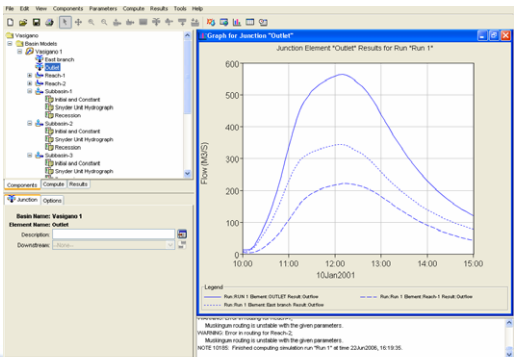
Creating a basin model



Summary of results



Summary of results -graphs



Exercise – Use of HEC-HMS to generate flood hydrographs

Problem statement

This example shows how to derive a flood hydrograph for the Vaisigano catchment using observed rainfall. The Vaisigano catchment has a catchment area of 33 km^2. There are three rain gauges in the Vaisigano catchment called: Apia, Vaisigano East and Upstream. The objective of the exercise is to estimate the effect of proposed future urbanisation in the catchment on flood flows. The catchment is shown in Figure 1.

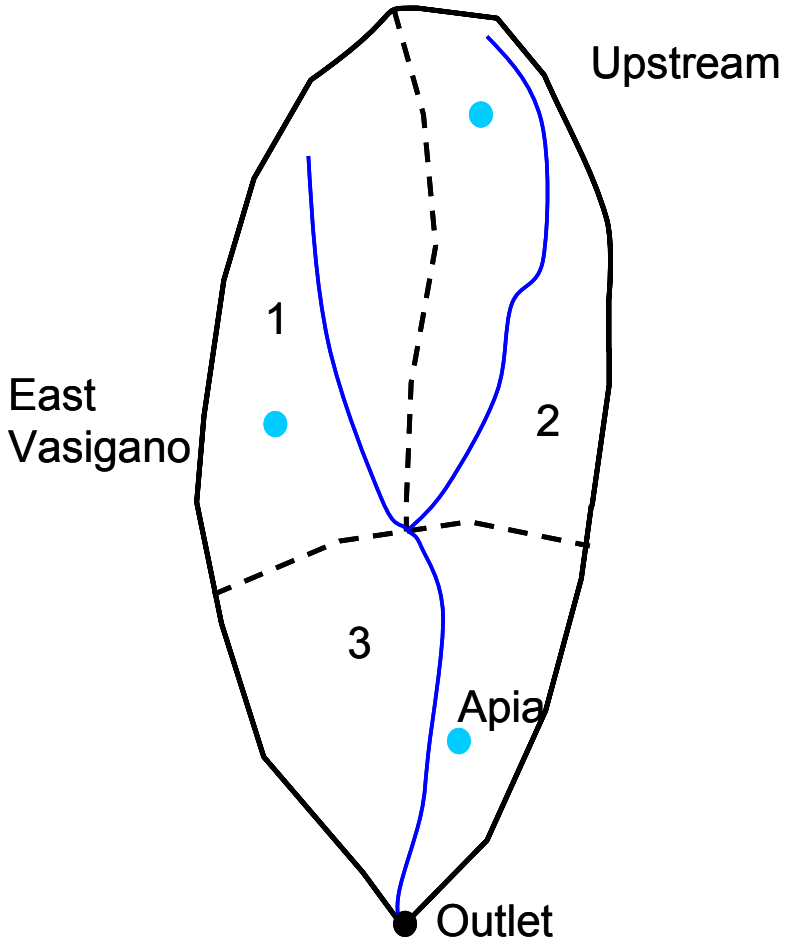


Figure 1 Schematic diagram of the Vaisigano catchment

This example will require you to create a new project an entering gauge data. A basin model using the initial constant loss, Snyder unit hydrograph and recession baseflow methods will be created from the parameters shown in the Tables below.

Table 1 Vaisigano east rain gauge

Date and time	Rainfall (mm)
10 Jan 2001 10:00	0
10 Jan 2001 10:15	50
10 Jan 2001 10:30	80
10 Jan 2001 10:45	40
10 Jan 2001 11:00	40
10 Jan 2001 11:15	20

Table 2 Subbasin initial and constant loss methods and Synder unit hydrograph

Subbasin	Loss parameters			Snyder unit hydrograph	
ID	Initial (mm)	Constant (mm/hour)	Impervious area (%)	Tp (hours)	Cp
1	15	10	1	0.20	0.16
2	15	10	1	0.20	0.16
3	15	10	1	0.20	0.16

Table 3 Subbasin area and baseflow data

Subbasin Parameters		Baseflow parameters		
ID	Area (km^2)	Initial flow ($m^3/s/km$)	Threshold (ratio to peak)	Recession (constant)
1	10	0.5	0.1	0.79
2	8	0.5	0.1	0.79
3	15	0.5	0.1	0.79

Table 4 Routing criteria for reaches

ID	From	To	Method		Parameters
Reach-1	Subbasin-1	Junction-1	Muskingum		K = 0.5 hours, x = 0.2
Reach-2	Subbasin-2	Junction-2	Muskingum		K = 0.3 hours, x = 0.2

A meteorologic model will have to be created for the precipitation data. Thiessen polygon weights, detailed in Table 5, will be used for the user gauge weithing precipitation method. The total rainfall measured at Apia was 150 mm and at a climate station in the upstream part of the catchment a total rainfall of 250 mm was recorded. The storm rainfall is to be distributed in time using the temporal pattern of incremental rainfall from the Vaisigano East gauge. The Vaisigano East rainfall data will be entered manually.

Table 5 Precipitation rain gauge weights

Subbasin	Apia	Vasigano East	Upstream gauge
1	0.00	0.25	0.75
2	0.10	0.70	0.20
3	0.90	0.10	0.00

A simulation run will be carried out for the existing catchment conditions to determine the existing rainfall – runoff response. Finally future urbanisation of the catchment will be modelled and the results compared to the existing conditions.

Create a subdirectory

Create a subdirectory on your computer called C:\Hmsproj using Windows Explorer.

Create the project

Begin by starting HEC-HMS and creating a new project. Select the **File → New…**menu item. Enter `Vaisigano` for the project "Name" and `Vaisigano land use change study` for the description, as shown in Figure 2 below. Project files will be stored in a directory called Vasigano a subdirectory of C:\Hmsproj. Set the default unit system to `Metric` and click the create button to create the project.

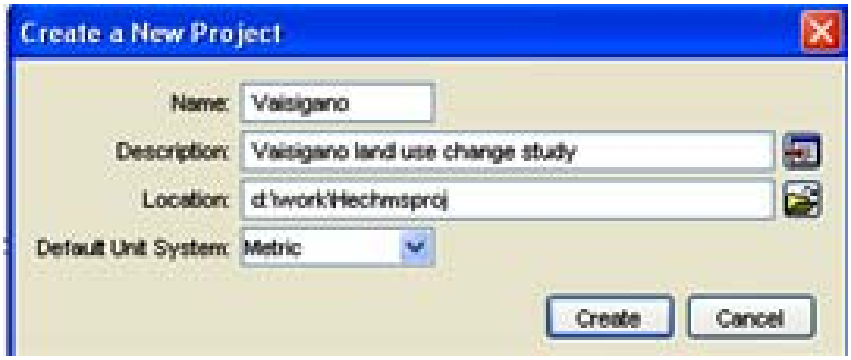


Figure 2 Enter the name, description and default unit system of the new project

Set the project options before creating the gages or model components as shown in Figure 3. Select the **Tools → Project Options….**menu item. Set "Loss" to `Initial and Constant`, "Transform" to `Snyder Unit Hydrograph`, "Baseflow" to `Recession`, "Routing" to `Muskingum`, "Precipitation" to `Gage Weights`, "Evapotranspiration" to `None` and "Snowmelt" to `None`. Click the **OK** button and close the *Project Options* window.

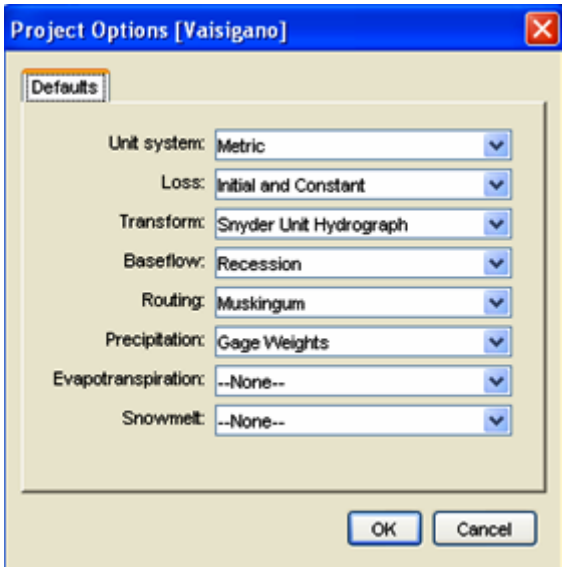


Figure 3 Enter the project options

Input data

Create a precipitation gage for the `Vaisigano East` data. Select the **Components → Time-Series Data Manager** menu item. Make sure the "Data Type" is set to `Precipitation Gages`. Click the New…button in the Time-Series Data Manager window. In the *Create A New Precipitation Gage* window enter `Vaisigano East` for the "Name" and `Vaisigano East rain gauge` for the "Description". Click the Create button to add the precipitation gauge to the project. The `Vasigano East` precipitation gauge is added to the **Precipitation Gages** folder under the **Time-Series Data** folder in the *Watershed Explorer*. Click the plus sign next to the gauge name. The *Watershed Explorer* expands to show all time windows for the precipitation gauge. A default time window was added when the gauge was created. Select the time window in the Watershed Explorer to show all the time windows for the precipitation gauge. Select "Manual Entry" from the Data Source dropdown menu and a Time Interval of 15 minutes from the dropdown menu as shown in Figure 4.

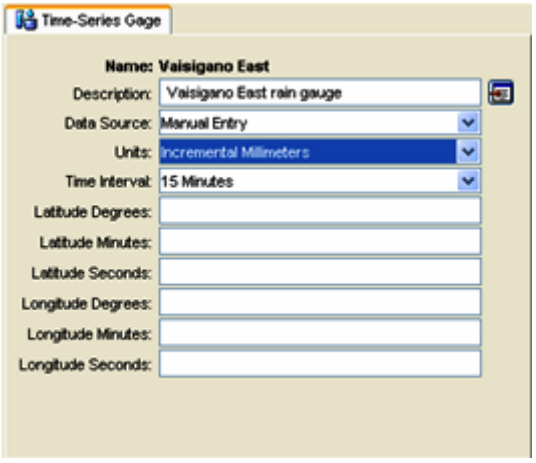


Figure 4 Time series gauge for Vaisigano East rain gauge set up

In the *Watershed Explorer* window double click on the `Vaisigano East` precipitation gauge. In the *Component Editor* open the "Time Window" tab and change the "Start Date" and "End Date" to `10Jan2001`. Change the "Start Time" to `10:00` and the "End Time" to `11:15` as shown in Figure 5.

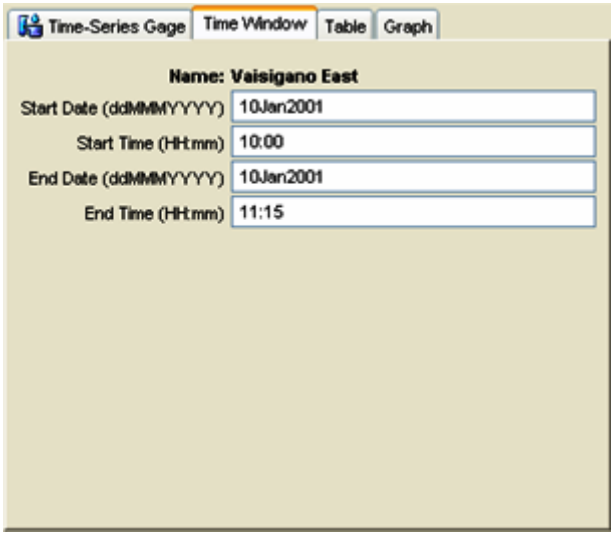


Figure 5 Time Window data for the Vaisigano East gauge

Enter the Vaisigano rainfall data from Table 1 into the "Table" tab under the *Component Editor* as shown in Figure 6.

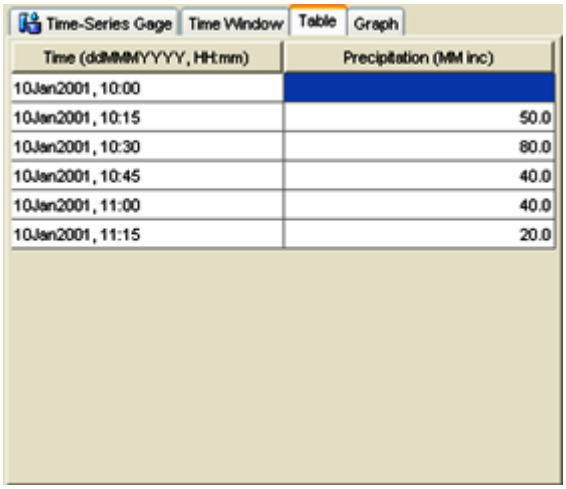


Figure 6 Manual entry of the rainfall data

A plot of this data can be viewed by clicking on the "Graph" tab.

Creating the basin model

Begin by creating the basin model by selecting **Components → Basin Model Manager** menu item. Create a new basin model with a "Name" of `Vaisigano 1` and a "Description" of `Existing conditions`.

Create the element network

The Vaisigano catchment will be represented with three subbasins, two routing reaches and two junctions. Use the following steps and Figure 7 to create the element network.

1. Add the three sub basin elements. Select the subbasin icon on the tool bar. Place the subbasin icons by clicking the left mouse in the Desktop window.

2. Add the two reach elements.

3. Add the two junction elements.

4. Connect Subbasin-1 to Reach-1. Place the mouse over the subbasin icon and click the right mouse button. Select the Connect Downstream menu item. Place the mouse over the upstream end of the reach icon and click the left mouse button. A connection link shows the elements are connected.

5. Connect the other element icons using the same procedure used to connect Subbasin-1 downstream to Reach-1. Move the hydrologic elements as necessary to complete the network shown in Figure 7. Move an element by placing the mouse over the icon in the basin model map. Release the left mouse button to place the icon. The upper and lower ends of a reach element icon can be moved independently.

Figure 7 Subbasin, reach and junction elements in their correct position

Enter the element data

Enter the area for each subbasin element detailed in Table 3, shown in Figure 8. Select a subbasin element in the *Watershed Explorer* or the basin model map. Then, in the *Component Editor* select the "Subbasin" tab and enter the subbasin area. Enter the basin area for all the subbasin elements. One way of entering parameter data for a subbasin element is to click on each of these tabs and enter the required information. Another way to enter parameter data is to use the global editors. Global editors are the most efficient way to enter data for several subbasin and reach elements that use the same methods. Subbasin area can also be entered using a global editor by selecting the **Parameters→ Subbasin area** menu item. Select the **Parameters→ Loss →Initial and constant** menu item to open the *Initial Constant Loss* global editor, see Figure 9. Change the *Snyder Transform* values using the same process, see Figure 10 and the *Recession Baseflow* values see Figure 11.

Change the name of the three junction elements. Click the right mouse button when the mouse is on top of the Junction-1 element name in the *Watershed Explorer.*and select the **Rename…** option in the popup menu. Change the name to `Outlet`. Change the name of Junction-2 to `East Branch`.

Enter the parameter data for each of the reach elements. Open the *Component Editor* for `Reach-1`. Click the "Route" tab in the *Component Editor* and add the `Reach-1` data. Do the same for `Reach-2`.

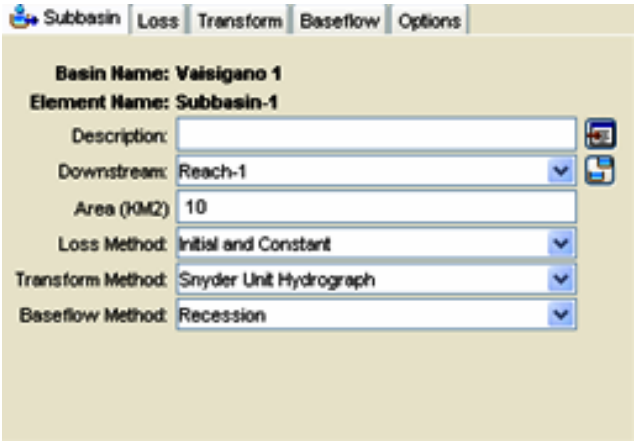


Figure 8 Subbasin area

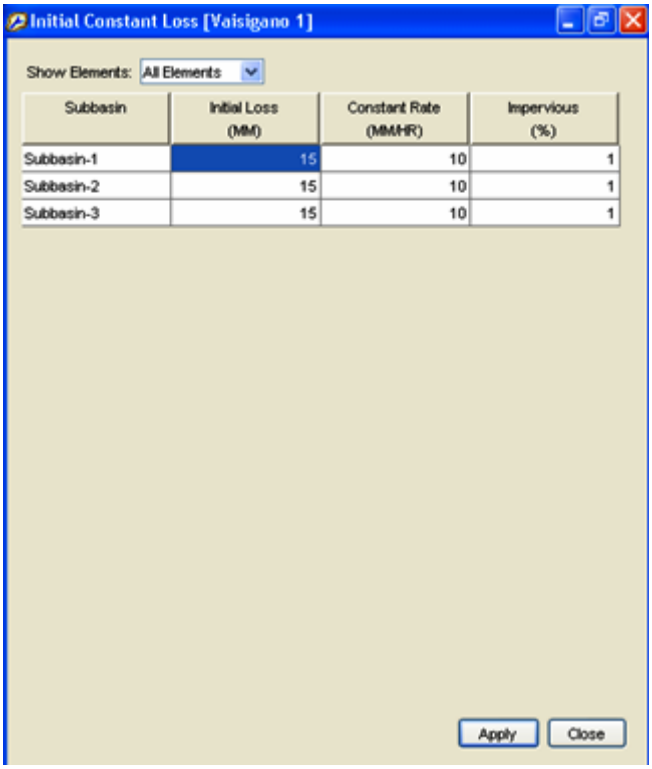


Figure 9 Initial and constant loss global editor

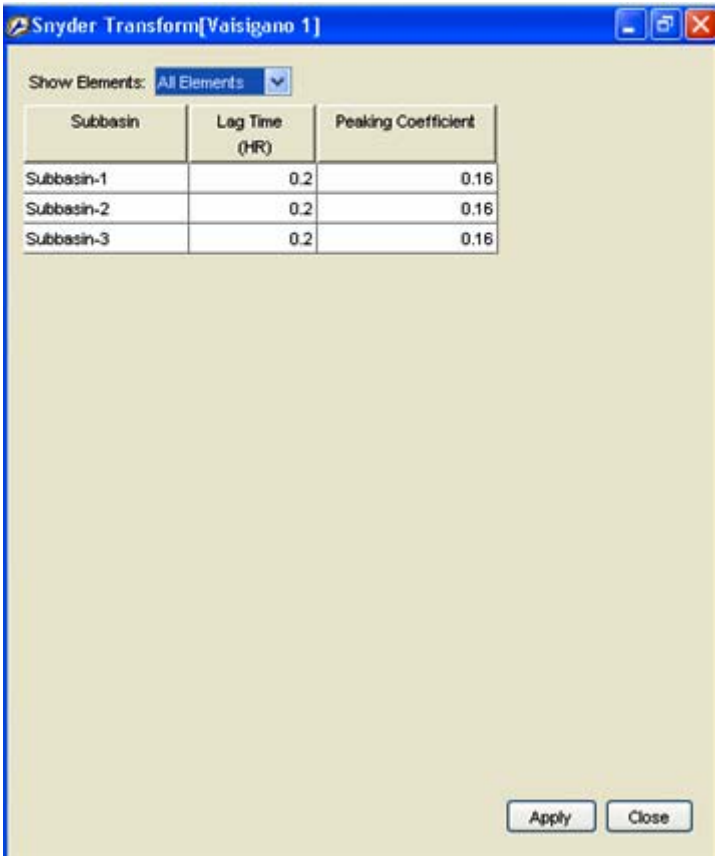


Figure 10 Snyder transform global editor

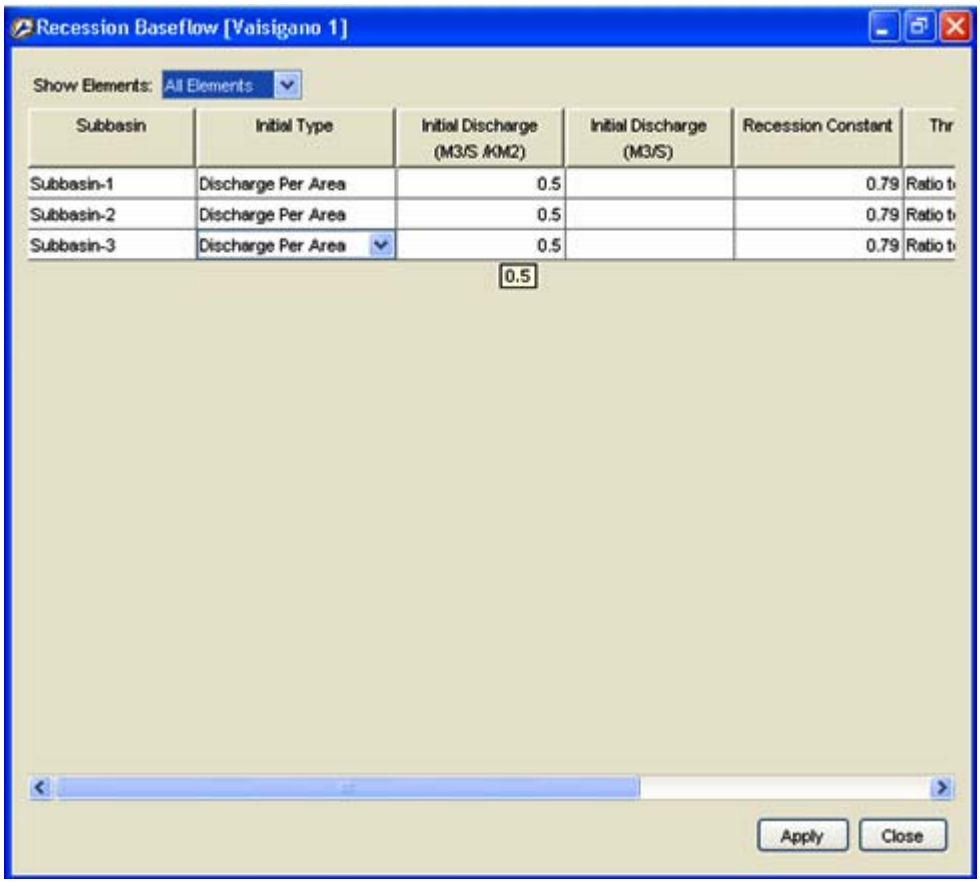


Figure 11 Recession baseflow global editor

Change the name of the three junction elements. Click the right mouse button when the mouse is on top of the Junction-1 element name in the *Watershed Explorer* and select the **Rename…** option in the popup menu. Change the name to `West Branch`. Change the name of the Junction-2 element to `Outlet`.

Open the *Component Editor* for `Reach-1` and Rreach-2 and enter the detail from Table 4, see Figure 12.

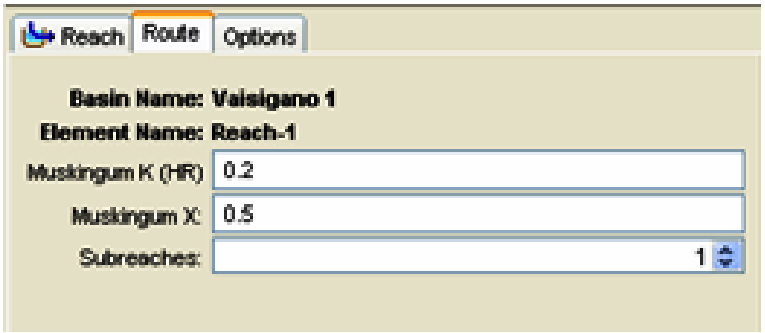


Figure 12 Muskingum data for Reach-1

Create the Meteorologic model

Begin creating the meteorologic model by selecting the **Components→ Meteorologic Model Manager** menu. Click the **New…**button in the *Meteorologic Model Manager* window. In the *Meteorologic Model Manager* window enter `Gauge weights` for the "Name" and `Thiessen weights 15 minute data` for the "Description". Open the *Component Editor* for the meteorologic model by selecting the *Watershed Explorer*. In the *Component Editor* make sure the selected "Precipitation" method is `Gage Weights`, see Figure 13.

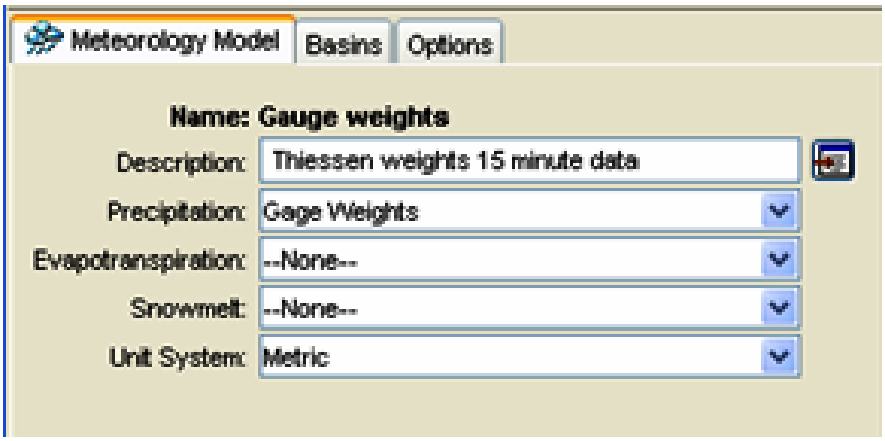


Figure 13 Component Editor for Meteorologic model

Subbasins need to be specified for this meteorologic model. Click the "Basins" tab in the *Component Editor* for the `Gauge weights` meteorologic model. Set the "Include Subbasins" to "Yes" for the `Vaisigano 1` basin model, see Figure 14. After this step all subbasins in the `Vaisigano 1` basin model are added to the meteorologic model.

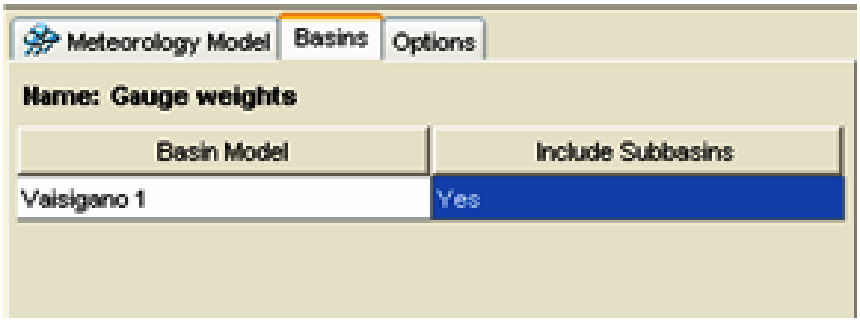


Figure 14 Include subbasins in Meteorologic model

Use the following steps and Figure 15 to complete the Gauge weights meteorologic model:

1. Add the Apia and upstream catchment total rainfall amounts to the meteorologic model. Select the **Precipitation Gages** element in the *Watershed Explorer* to open the "Total Storm Gages" editor. This element should be located one level

under the meteorologic model. Enter `Apia` for the "Gage Name" and `150` for the "Total Depth". Add the `Upstream gauge` total rainfall in the same way – note the total rainfall for this gauge is 250 mm.

Total Storm Gages

Name: Gauge weights

Gage Name	Total Depth (MM)
Apia	150
Upstream	250

Figure 15 Apia and upstream Total Storm Gages

2. In the *Watershed Explorer*, click the plus sign next to the **Subbasin-1** element and select the **Gage Weights** sub component, see Figure 16. A *Component Editor* will open with two tabs, "Gage Selections" and "Gage Weights". Depth and time weights are required for all precipitation gauges with the "Use Gage" option set to "Yes". For this example the `Vasigano East` gauge will be used for all subbasin elements because it contains the storm pattern; the other gauges only contain total storm depths. Once the correct precipitation gauges are included for `Subbasin-1`, select the "Gage Weights" tab and enter the correct "Depth Weight" from Table 5 for `Subbbasin-1`. The "Time Weight" will be 1.0 for the `Vasigano East` gauge in all the subbasins, see Figure 17. Complete this step for the remaining subbasins.

Gage Selections | Gage Weights

Name: Subbasin-1

Gage Name	Use Gage
Apia	No
Upstream gauge	Yes
Vasigano East	Yes

Figure 16 Apia and upstream Total Storm Gages

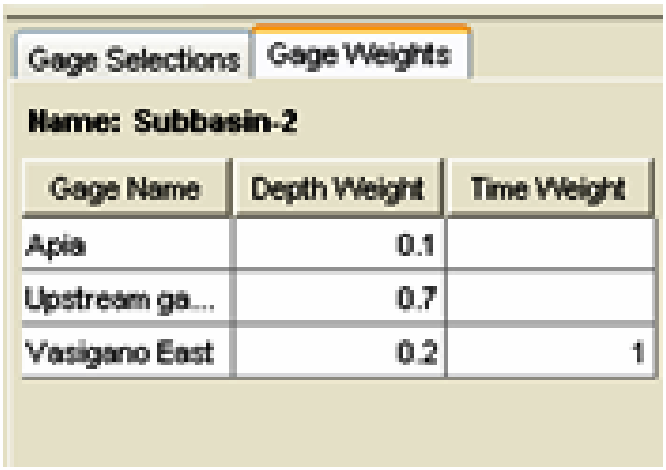


Figure 17 Gauge weights for Subbasin-2

Define the control specifications

Create the control specifications by selecting **Components →Control Specifications Manager** menu item. In the *Control Specifications Manager* window click the **New…** button and enter `Jan2001` for the "Name" and `10 January 2001` for the "Description". In the Component Editor, enter `10Jan2001` for both the "Start Date" and the "End Date". Enter `10:00` for the "Start Time" and `15:00` for the "End Time". Select a time interval of `5 minutes` from the "Time Interval" drop-down list, see Figure 18.

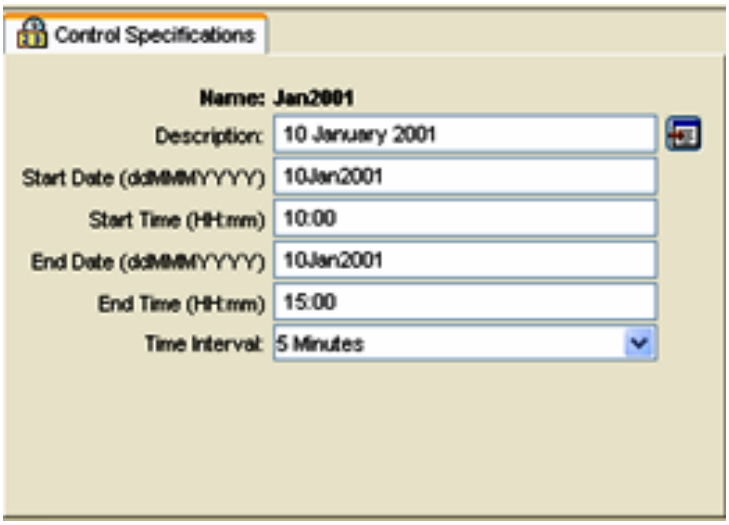


Figure 18 Entering control specifications data

Create and compute a simulation run

Create a simulation run by selecting the **Compute →Create Simulation Run** menu item. Keep the default name `Run 1`. Select the `Vasigano 1` basin model, `Gauge weights` meteorologic model and `Jan2001` control specification using the wizard. After the wizard closes select the "Compute" tab of the *Watershed Explorer*. Select the **Simulation Runs** folder so that the *Watershed Explorer* expands to show **Run 1**.

Click on **Run 1** to open the *Component Editor* for the simulation run. Change the description for this simulation run by entering `Existing conditions, 10 January 2001 storm`, see Figure 19.

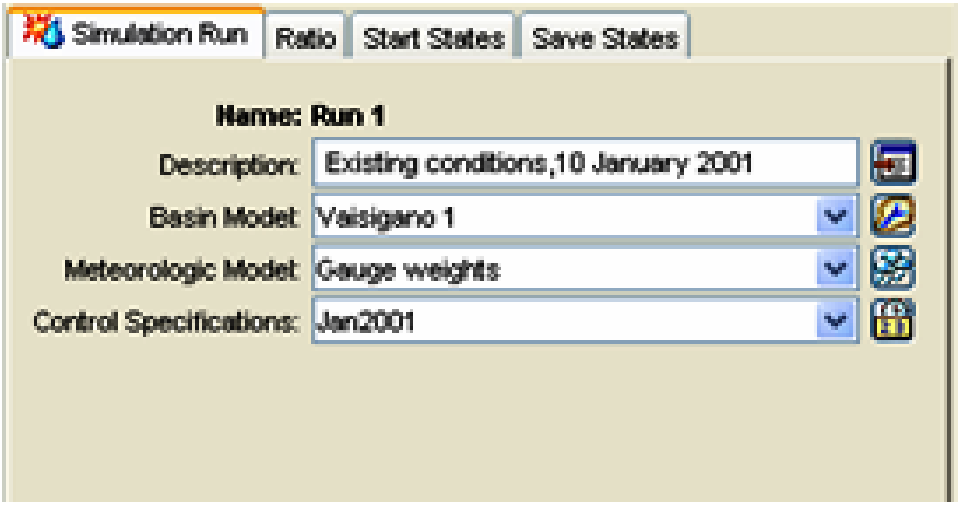


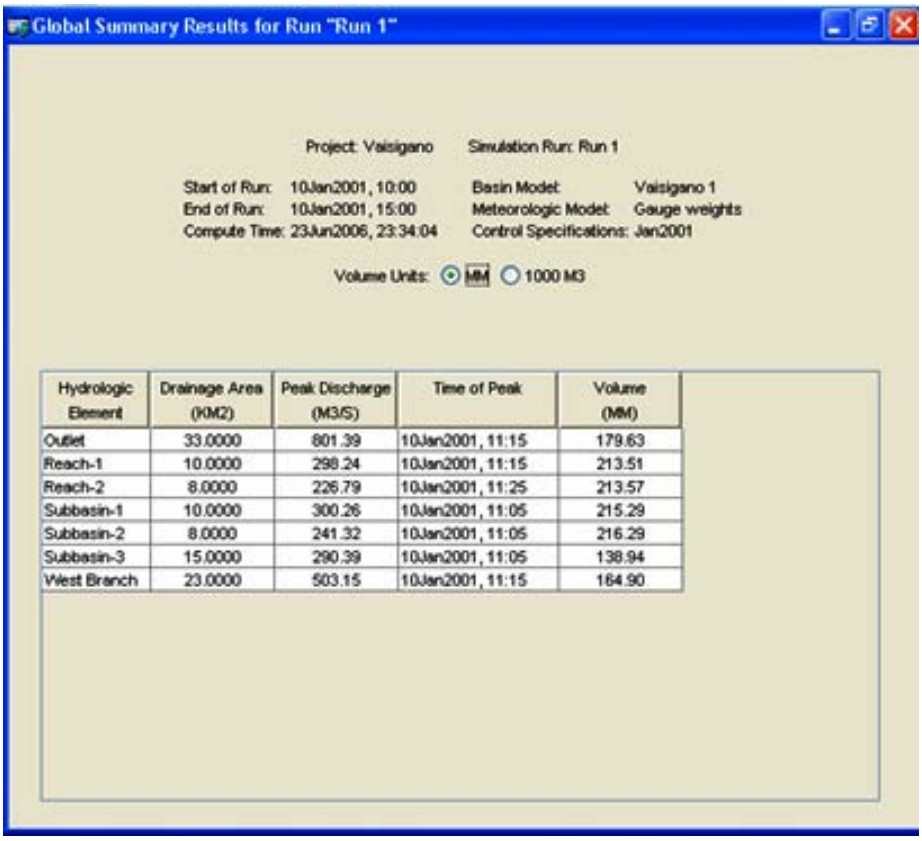
Figure 19 Component editor for simulation run

Click the right mouse button when the mouse is on top of the **Run 1** name in the *Watershed Explorer* and select the **Compute** option in the popup menu. A window opens showing the progress of the run. Close this window when the run finishes.

View model results

Begin viewing the results by opening the basin model map. Open the `Vaisigano 1` basin model map by clicking on the name on the *Watershed Explorer*, "Components" tab.

Select the **Global Summary Table** tool from the tool bar to view the summary results of the peak flows for all the elements in the basin model see Figure 20. Make a note of the computed peak discharge for the Junction element named Outlet. View graphical and tabular results for the Junction element named Outlet. Place the mouse over the Outlet icon in the basin model map and click the right mouse button. Select the **View Results →Graph** menu item see Figure 20. Select the **View Results →Summary Table** menu item to view the subbasin element time series table see Figure 20. Select the **View Results →Time-Series Table** menu to view the subbasin time-series table, see Figure 21.


Global Summary Results for Run "Run 1"
Project: Vaisigano Simulation Run: Run 1
Start of Run: 10Jan2001, 10:00
End of Run: 10Jan2001, 15:00
Compute Time: 23Jun2006, 23:34:04
Basin Model: Vaisigano 1
Meteorologic Model: Gauge weights
Control Specifications: Jan2001
Volume Units: MM 1000 M3

Hydrologic Element	Drainage Area (KM2)	Peak Discharge (M3/S)	Time of Peak	Volume (MM)
Outlet	33.0000	801.39	10Jan2001, 11:15	179.63
Reach-1	10.0000	298.24	10Jan2001, 11:15	213.51
Reach-2	8.0000	226.79	10Jan2001, 11:25	213.57
Subbasin-1	10.0000	300.26	10Jan2001, 11:05	215.29
Subbasin-2	8.0000	241.32	10Jan2001, 11:05	216.29
Subbasin-3	15.0000	290.39	10Jan2001, 11:05	138.94
West Branch	23.0000	503.15	10Jan2001, 11:15	164.90

Figure 20 Viewing the global summary table

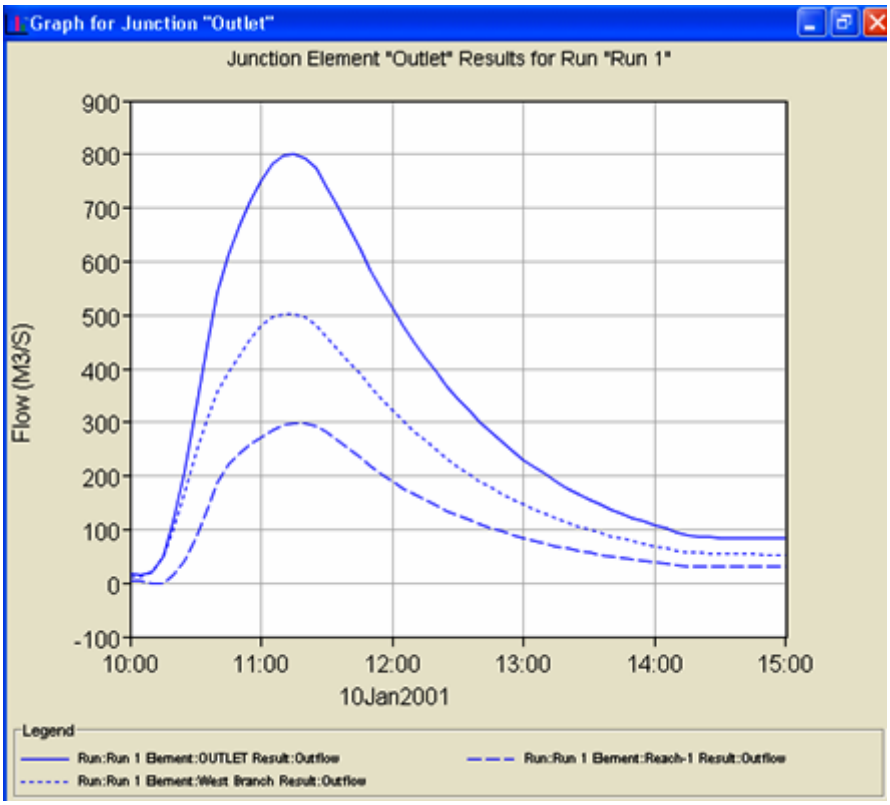


Figure 21 Graph of outlet results

Simulate future urbanisation

Consider how the Vasigano catchment would respond given the effects of future urbanisation. The meteorologic and control specifications remain the same, but a modified basin model must be created to reflect the anticipated changes to the catchment.

Create the modified basin model

The urbanised basin model can be created by modifying a copy of the existing conditions basin model. Place the pointer on the `Vaisigano 1` basin model in the *Watershed Explorer*, "Component" tab, and click the right mouse button. Select the **Create Copy…**option. Enter `Vaisigano 2` as the basin model "Name" and `Future` conditions for the "Description" in the *Copy Basin Model* window.

Modify the new basin model to reflect possible future urbanisation. Open the Component Editor for each of the three subbasins (select the subbasins in the Watershed Explorer or in the basin model map). Change the percentage impervious area to 15% for each of the three subbasins.

Update the `Gauge weights` meteorologic model to include the subbasins from the `Vaisigano 2` basin model. Select the meteorologic model in the *Watershed Explorer* to open the *Component Editor*. Open the "Basins" tab and change the "Include Subbasins" option to "Yes" for the `Vaisigano 2` basin model.

Urbanised simulation run

Create a new simulation run for the future conditions basin by selecting the **Compute → Create Simulation Run** menu item. Keep the default name of `Run 2` and select the `Vaisigano 2` basin model, the `Gauge weights` meteorologic model and the `Jan2001` control specifications using the wizard. Open the *Component Editor* for `Run 2` and enter `Urbanised conditions, 10 Jan 2001 storm` as the description. Compute `Run 2` and compare the peak discharges for the urbanised conditions with the existing conditions at the Outlet.

Results from the two simulations can also be compared from the "Results" tab of the *Watershed Explorer*. Results are available as long as no modifications have been made to components used by the simulation run. For example if a constant loss parameter was changed in a subbasin element, then the results for all simulation runs in which the subbasin element resides will not be available. It is easy to determine if results are available. If the simulation run icon is grey, then results are not available and the simulation must be re-run.

Use the *Watershed Explorer* to compare results from Run 1 and Run 2. Click the "Results" tab in the *Watershed Explorer* and select both simulation runs. The *Watershed Explorer* expands to show all the hydrologic elements with results. Then select, the Outlet junction and watch the *Watershed Explorer* expand to show all the

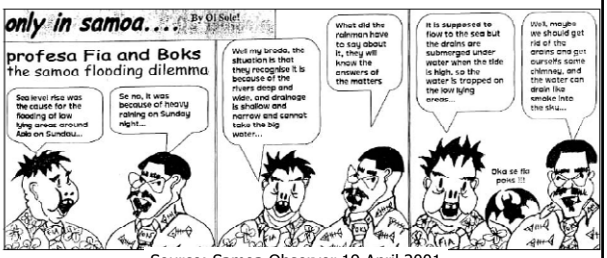
Day 3

Introduction to the training

River modelling and flood mapping

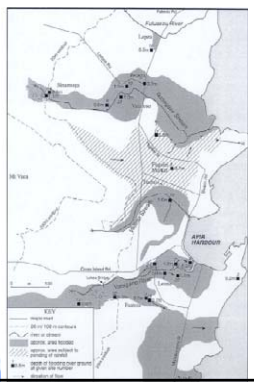
Why model rivers?

Why map floods?


only in samoa...
By Oi Sole!
profesa Fia and Boks
the samoa flooding dilemma
Sea level rise was the cause for the flooding of low lying areas around Apia on Sunday...
So no, it was because of heavy raining on Sunday night...
Well my broda, the situation is that they recognise it is because of the rivers deep and wide, and drainage is shallow and narrow and cannot take the big water...
What did the rainman have to say about it, they will know the answers of the matters
It is supposed to flow to the sea but the drains are submerged under water when the tide is high, so the water is trapped on the low lying areas...
Well, maybe we should get rid of the drains and get ourselfs some chimney, and the water can drain like smoke into the sky...
Oka se fia pona !!!

Source: Samoa Observer 19 April 2001

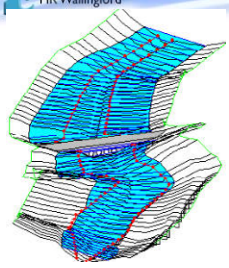
2001 flooding in Apia



Programme

- Concepts and principles of hydraulics
- River modelling
- River resistance and roughness
- River morphology
- Methods of flood defence
- Risk and uncertainty
- Use of HEC-RAS modelling software

Ultimate objectives



River model

Hazard = Flood map

Risk =
Damage to infrastructure, buildings, harm to people

Concepts and principles in hydraulics

Learning objectives

- Different principles of flow states
- Definition and calculation: uniform flow, conveyance and flow resistance
- Typical water surface profiles for various conditions

Skills acquired

- To be able to understand different hydraulic terminology
- To be able to use simple hydraulic equations

What is hydraulics?

- Study of how water moves
- Deterministic based on mass conservation and force balance
- Uses principles of momentum and energy transfer
- Provides water levels, velocities, flow rates

Links to other areas

Water resources -
- What are water levels for different flows in different seasons

River morphology -
- sediment carrying capacity

Water quality -
- velocities associated with flows and channel shapes and sizes

Open channel principles

- Energy and Momentum
- Uniform flow
  - Channel conveyance
  - Resistance equations
- States of flow
- Water surface profiles

Energy and Momentum

Energy is the "capacity" to do "work"

- Kinetic energy (from speed)
- Potential energy (from position)
- Also heat, sound etc
- Each type has a magnitude (value) only
- Energy "balance" on streamlines
- Total Energy is conserved

Energy "losses" arise because some energy types are ignored in analysis

Energy and Momentum

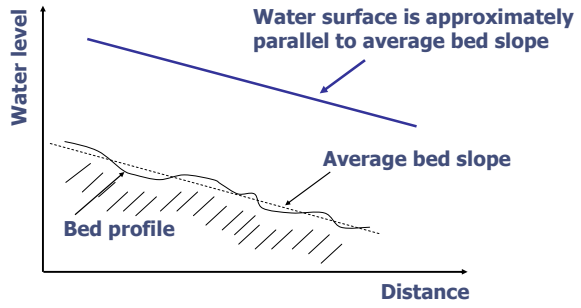
Momentum is mass times velocity

- Changed by forces and impulses
- Use Newton's second law
- Has magnitude and direction
- Used to calculate forces on structures
- Can be applied where energy "losses" are large

Scope for confusion!

Uniform Flow

Uniform flow profile



Uniform flow

Central to understanding of open channel hydraulics

Energy "line", water surface slope and channel bed are all parallel

The depth is called "Normal Depth"

Several assumptions in the analysis

Rarely occurs in practice!

Calculating uniform flow

Assumptions are:

- steady flow
- regular shape of cross-section
- no change of velocity, depth or slope with distance along channel
- rate of "loss" of potential energy balances work done against flow resistance - but ...

What is really happening?

Uniform flow equation

Equation relating slope, channel dimensions and velocity

$$Q = K s^{1/2}$$

- Q is discharge
- K is conveyance
- s is water surface slope

Conveyance represents the flow capacity of the channel

What is conveyance?

Links channel dimensions, shape and roughness - many formulae available

Manning's equation:

$$K = \frac{A R^{2/3}}{n}$$

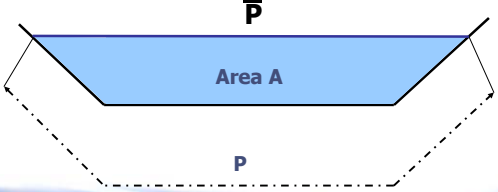
- K is conveyance
- A is area
- R is hydraulic radius
- n is Manning's roughness coefficient

Hydraulic radius

Represents the shape of the cross section

Ratio of Area, A to Wetted Perimeter, P

$$R = \frac{A}{P}$$



Putting things together

$$Q = K s^{1/2}$$

$$K = \frac{A R^{2/3}}{n}$$

$$R = \frac{A}{P}$$

$$Q = \frac{(A^{5/3} s^{1/2})}{n P^{2/3}}$$

Given a section shape, we can calculate A and P

With information on slope and roughness we can calculate discharge

What is the roughness coefficient?

A number which describes the resistance of the channel to flow

Depends upon the resistance equation being used

We concentrate on Manning's equation due to its international use

It has limitations e.g. varies with depth

What affects roughness?

Bed surface material

Channel irregularity

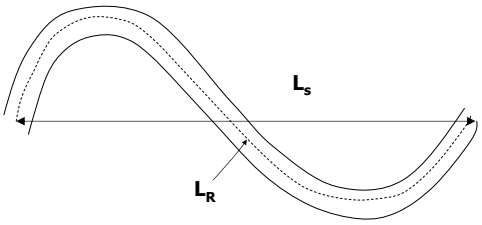
Channel alignment and sinuosity

Depth and discharge velocity

Vegetation and sediments

Altitude or gradient (as surrogates for other parameters)

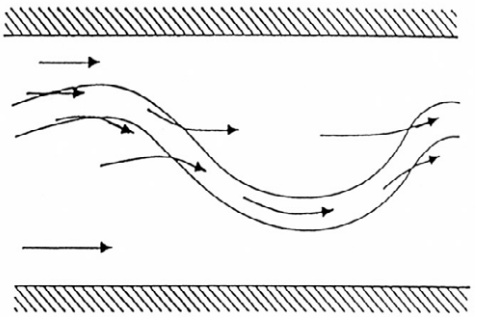
Sinuosity



Sinuosity $S = \frac{L_R}{L_S}$

Sinuous River

Interaction between channel and floodplain



Evidence of flow interaction

Classification of flows

Flow states

Sub-critical

- Slow and deep - low kinetic energy

Super-critical

- Fast and shallow - high kinetic energy

Critical

- Special, unique relation between velocity and "mean" depth, y

$$V_c = (gy)^{1/2}$$

Alternative classification

Froude number

$$Fr = \frac{V}{(g\,y)^{1/2}}$$

where V is velocity (m/s),

y is depth (m)

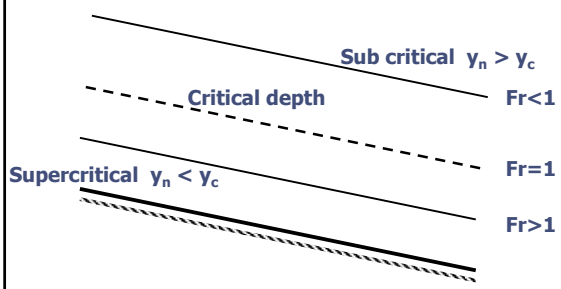
g is acceleration due to gravity (m^2/s)

Fr < 1 subcritical flow

Fr = 1 critical flow

Fr > 1 supercritical flow

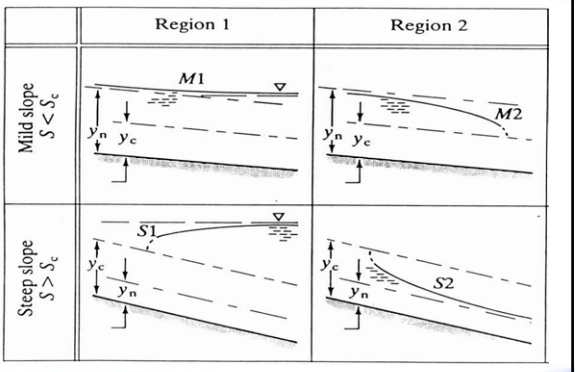
Normal and critical depths



Transition - Hydraulic jump

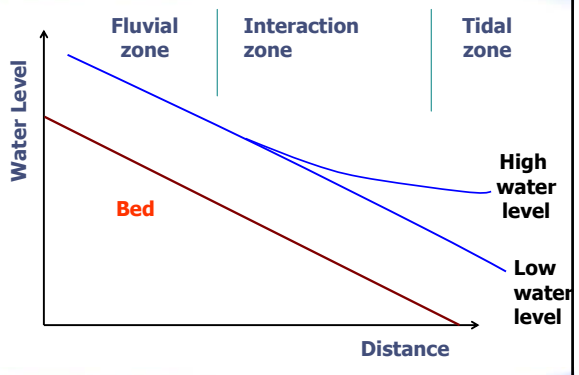
Interpreting flow profiles

Non-uniform flow profiles



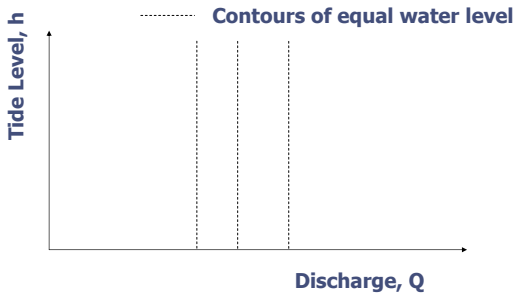
Page 29

Tidal river flood profiles

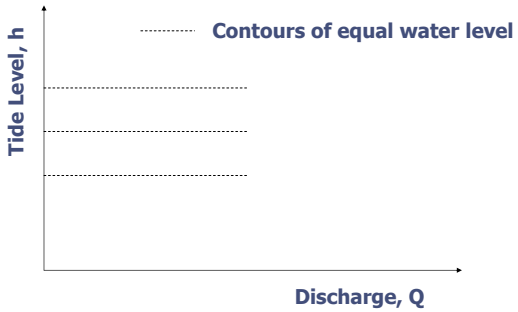


Page 30

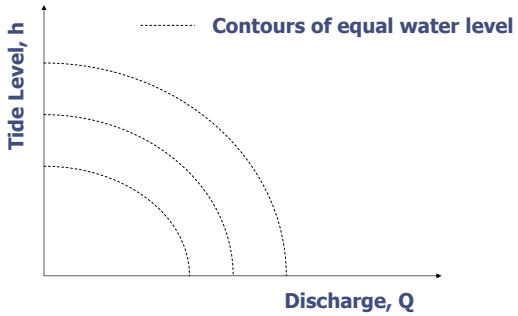
Fluvial zone



Tidal zone



Transitional zone



What have we learnt?

Simple principles of different flow states

Definition and calculation of :

- **Uniform flow**
- **Conveyance**
- **Flow resistance**

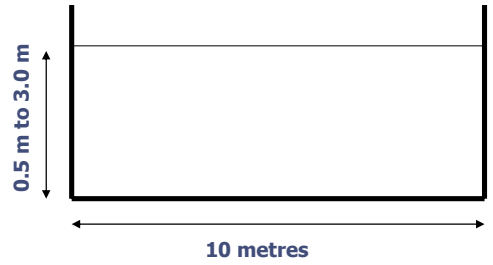
Typical water surface profiles for various conditions

Exercise

Principles in hydraulics

The geometry

Rectangular channel (for simplicity)



The numbers

- Water flows in an open rectangular channel 10 m wide
- Consider depths between 0.5 m and 3 m in 0.5 m steps
- Manning's n = 0.04, 0.03, 0.02
- Slope 1 in 500, 200 and 100
- Calculate discharge, velocity and Froude number

Work in a group

Choose some cases and share the results in the group

- How sensitive is discharge to depth?
- How sensitive is velocity to depth?
- How sensitive is Froude number to depth?

What happens for different slopes and roughnesses?

What is the critical slope for n = 0.02?

The worksheet

Worksheet for Exercise on Principles in Hydraulics

Manning's n =

Slope =

Width (m)	Depth (m)	Area (m^2)	Wetted Perimeter (m)	Hydraulic Radius (m)	Discharge (m^3/s)	Velocity (m/s)	Froude Number
10	0.5	5	11				
10	1	10	12				
10	1.5	15	13				
10	2	20	14				
10	2.5	25	15				
10	3	30	16				

Worksheet for exercise on principles in hydraulics: Rectangular channel

Manning's n =

Slope =

Ratio $s^{1/2}/n$ =

Width (m) B	Depth (m) y	Area (m^2) A	Wetted Perimeter (m) P = B + 2y	Hydraulic Radius (m) R = A/P	Discharge (m^3/s) $Q = AR^{2/3}s^{1/2}/n$	Velocity (m/s) V = Q/A	Froude Number $Fr = V/(gy)^{1/2}$
10	0.5	5	11				
10	1.0	10	12				
10	1.5	15	13				
10	2.0	20	14				
10	2.5	25	15				
10	3	30	16				

Worksheet for exercise on principles in hydraulics: Rectangular channel

Manning's n =

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Ratio $s^{1/2}/n$ =

Width (m) B	Depth (m) y	Area (m^2) A	Wetted Perimeter (m) P = B + 2y	Hydraulic Radius (m) R = A/P	Discharge (m^3/s) $Q = AR^{2/3}s^{1/2}/n$	Velocity (m/s) V = Q/A	Froude Number $Fr = V/(gy)^{1/2}$
10	0.5	5	11				
10	1.0	10	12				
10	1.5	15	13				
10	2.0	20	14				
10	2.5	25	15				
10	3	30	16				

Worksheet for exercise on principles in hydraulics: Rectangular channel

Manning's n =

Slope =

Ratio $s^{1/2}/n$ =

Width (m) B	Depth (m) y	Area (m^2) A	Wetted Perimeter (m) P = B + 2y	Hydraulic Radius (m) R = A/P	Discharge (m^3/s) $Q = AR^{2/3}s^{1/2}/n$	Velocity (m/s) V = Q/A	Froude Number $Fr = V/(gy)^{1/2}$
10	0.5	5	11				
10	1.0	10	12				
10	1.5	15	13				
10	2.0	20	14				
10	2.5	25	15				
10	3	30	16				

River modelling

Learning objectives

- To know the appropriate river model to use for various situations
- To understand modelling procedures
- To appreciate why calibration of models is important

Skills acquired

- To be able to distinguish between different types of river models
- To know the data requirements to construct a river model

Types of models

- Hydrological
- Detailed river flow
  - computational
  - physical
- Additions to flow models:
  - sediment, water quality

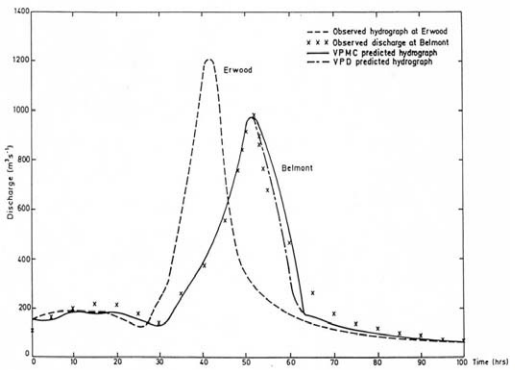
Hydrological models

- Prediction of river flows
  - rainfall-runoff models
  - statistical methods
- Catchment models
  - combined rainfall-runoff and flow routing
  - continuous simulation

Flow routing

- Discharge only with simple dynamics e.g. Muskingum Method (1934)
- Linearised methods in many models
- Cunge identified parameters identified with river process
- Variation of wave-speed and attenuation rate with discharge
- VPM-C method used for catchment modelling

Flow routing



Predicted and Observed Hydrographs for Flood of Dec1960, River Wye

Flow routing

Benefits

- limited data requirements
- quick and cheap to use

Limitations

- no water levels (except reservoirs)
- not suitable for flow reversal, looped systems and tidal systems

Hydrological design

Design storm depends on upstream characteristics, especially area

A single design storm to the outfall will not give design flows at all points across catchment

Critical duration of design storm will be shorter in upper catchment than lower catchment

Iterative process to get best compromise

Detailed river models

Predicts flows and water levels

Uses

- **Design of new works, for example:**
  - **flood defences**
  - **channel improvements**
  - **structures**
- **Impact of new works**

Detailed river models (continued)

Uses (continued)

- Operation of structures (e.g. gates)
- Producing flood maps
- Reconstruction of past floods
- Contingency planning
- Real time flood forecasting
- Fluvial/tidal interaction

River modelling - Hydrodynamics

Steady or unsteady flow ?

Require detailed topographic survey

Many available packages

Widespread use of implicit numerical methods to ensure robustness

Too easy to use?

Detailed computational river models

- Many standard commercial packages have one-dimensional hydraulics
- Steady flow
  - prediction of water surface profiles
  - use for short lengths of river (attenuation small)

Detailed computational river models

Unsteady flow

- Prediction of water level hydrographs
- Longer lengths of river (attenuation or storage important)
- Other unsteady effects (tides, flood storage, gate movement, etc)

River modelling software packages

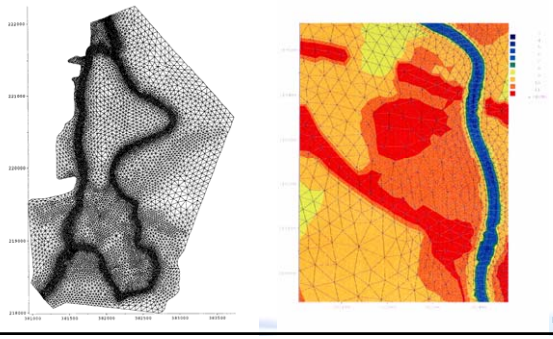
CARIMA	- SOGREAH
FLDWAV	- US NWS
iSIS	- HR Wallingford
HEC-RAS	- US Army of Engineers
MIKE11	- DHI
SOBEK	- Delft Hydraulics

River modelling – two dimensional modelling

- Based on shallow water theory
- Need irregular grids to fit natural topography
- Finite element models available commercially
- Computationally intensive
- Feasible to use in practice

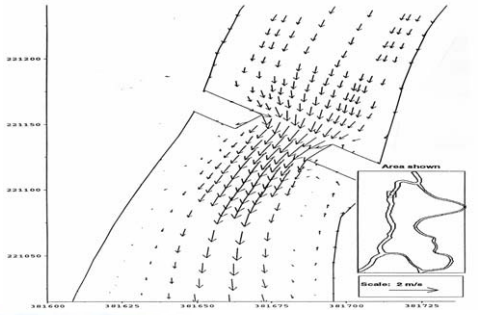
Two dimensional modelling

Channel and floodplain mesh



Two dimensional modelling

Velocity vector details



Detailed physical models

- Three-dimensional hydraulics
- Examine complex flow patterns
- Sites where one-dimensional hydraulics inappropriate
- Sites where accurate prediction essential
- Avoid scale effects

Detailed physical models

- Laboratory scale model
- Short lengths of river/complex geometry
- Hydraulic design of structures
- Typical scales:
  - Flood plain models 1:50 to 1:200
  - Structure models 1:10 to 1:50
- Good visual impact

Detailed physical models

Physical vs computational models

	Physical models	*Computational models*
Flow processes	Accurately reproduced	Empirical 1-D equations
Data needs	Intensive	Less intensive
Results	Detailed	Less detailed
Model extent	Small areas	Large areas
Presentation	Visual impact	Computer graphics
Future use	Cannot be stored	Can be stored

- Complementary use of models

Choice of model

Type of application

Data availability

Accuracy required

Time available

Nature of flow - steady or unsteady?

Choice of model

Each application has its own characteristics:

- **Planning (e.g. floodplain mapping, catchment development)**
- **Design (e.g. individual schemes)**
- **Forecasting**

Choice of model - planning

Standard scenarios (e.g. a future climate change situation)

Steady or unsteady

May use design methodology to set scenario (e.g. definition of large flood)

May use continuous simulation

Choice of model - design

Often a prescribed methodology

Models may be prescribed

Often based on hypothetical events

Continuous simulation a possible future approach

Choice of model - forecasting

Discharge forecasting or level forecasting?

Real-time application

Continuous simulation

Updating forecasts/error correction

Choice of model – steady or unsteady

- Gates
- Embankments
- Tides
- Storage important
- Timing important e.g. for different sub-catchments
- Attenuation through the reach

Choice of model – attenuation

Attenuation is important in:

- Long reaches
- Wide, flat flood plains
- Rapidly changing hydrographs

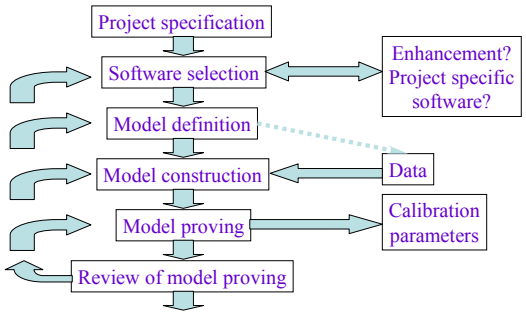
River modelling procedure

Need to formalise the use of models to avoid mistakes

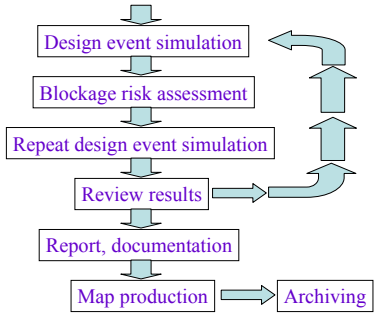
Generic description of the modelling process

Check, review and approve at key stages

Modelling procedure
Building phase



Modelling procedure
Predictive simulation phase



Data requirements

Maps

Topography

- **River channels**
- **Flood plains**
- **Embankments**

Structure details and channel section

Photographs (roughness estimates etc)

Data requirements (continued)

Boundary conditions for:

- Inflows
- Downstream water levels
- Rating curves

Calibration data including:

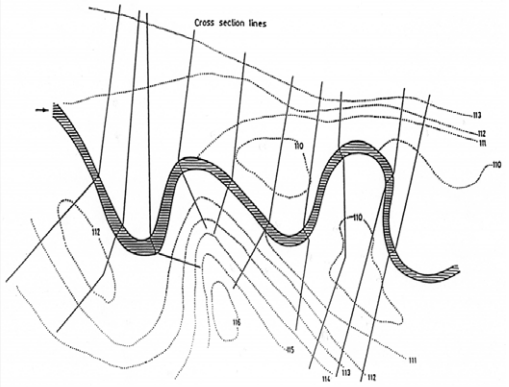
- Flows within the model area
- Water levels at key sites
- Flood outlines for maximum extent

Modelling spacing

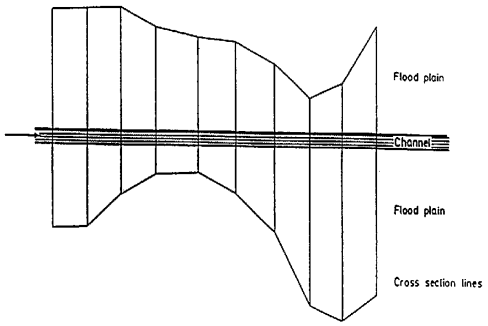
Slope (1 in …)	Section Spacing (m)
300 to 1 000	75
1 000 to 3 000	200
3 000 to 10 000	500
10 000+	1000

Contributes less than 30 mm to overall uncertainty

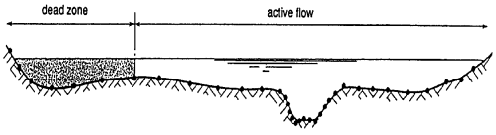
Typical one dimensional model layout

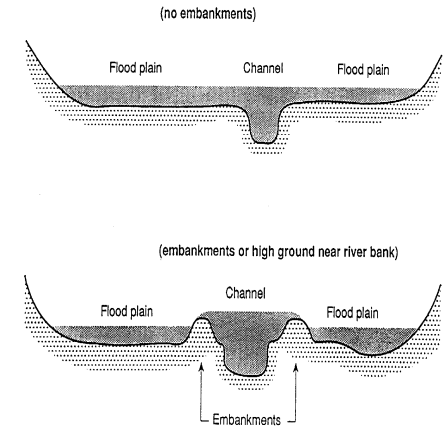


Typical one dimensional representation of the river



Adjustment of conveyance calculation





Use of calibrated model

- Match predicted and observed water levels/flows
- Inbank and overbank separately
- Calibrate and verify on independent events
- Adjust coefficients:
  - Channel and flood plain roughness
  - Structure discharge
- Uncertainties (blockages, bed movement etc)

Use of calibrated model

- Flood events of specified return periods (boundary conditions)
- Predict water levels for existing conditions
- Include proposed works in model
- Obtain water levels and compare with base data
- Iterate to optimum solution

How good is the answer?

- How good is the data?
- How good was the calibration?
- How far have you extrapolated from the calibration conditions?
- Be aware of uncertainties
- Sensitivity tests
- Realistic margin of safety

Exercise Approaches to river modelling

Undertake a group discussion to decide what type of model(s) and approaches you would use in the three cases described below. When deciding the best approach you will have to consider the following:

- What do you need to know?
- Scale (how big is the area of interest)?
- What is the minimum acceptable accuracy?
- How complex are the hydraulics
- How will the results be presented and who wants to see them.

When you have decided what type of models to use, you should also decide the approximate extent of river to be covered by the model.

Present you conclusions.

Case 1 Flood study for the town of Ba in Fiji

A major new commercial site has been proposed for the town of Ba in Fiji that has the River Ba running through the centre of it. Much of the development areas lay in areas that are likely to flood from the river. A study was needed to determine design flood levels in the development areas. The town is about 8 km from the sea and the river is tidal with a tidal range of about 1.0 m at the town.

The main cause of flooding at the town is from fluvial floods. Flow data are as follows:

Estimated design flood flow 1 in 100 years flow	600 m^3/s
Flood event in 2003	720 m^3/s
Flood event in 2001	270 m^3/s

The following maps are attached:

Figure 1 Map of Ba River catchment
Figure 2 Map of Ba town

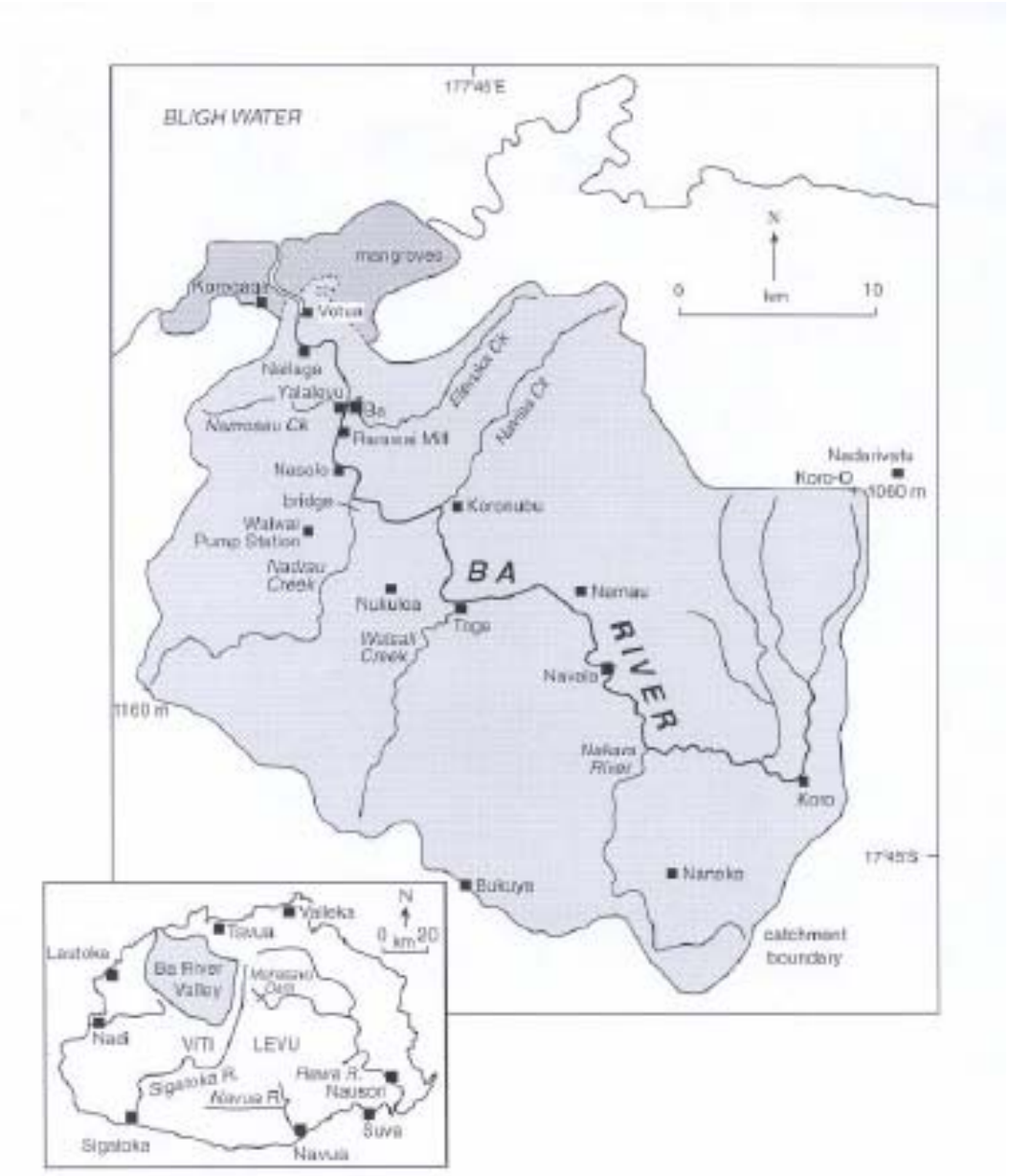


Figure 1 Map of the Ba River catchment

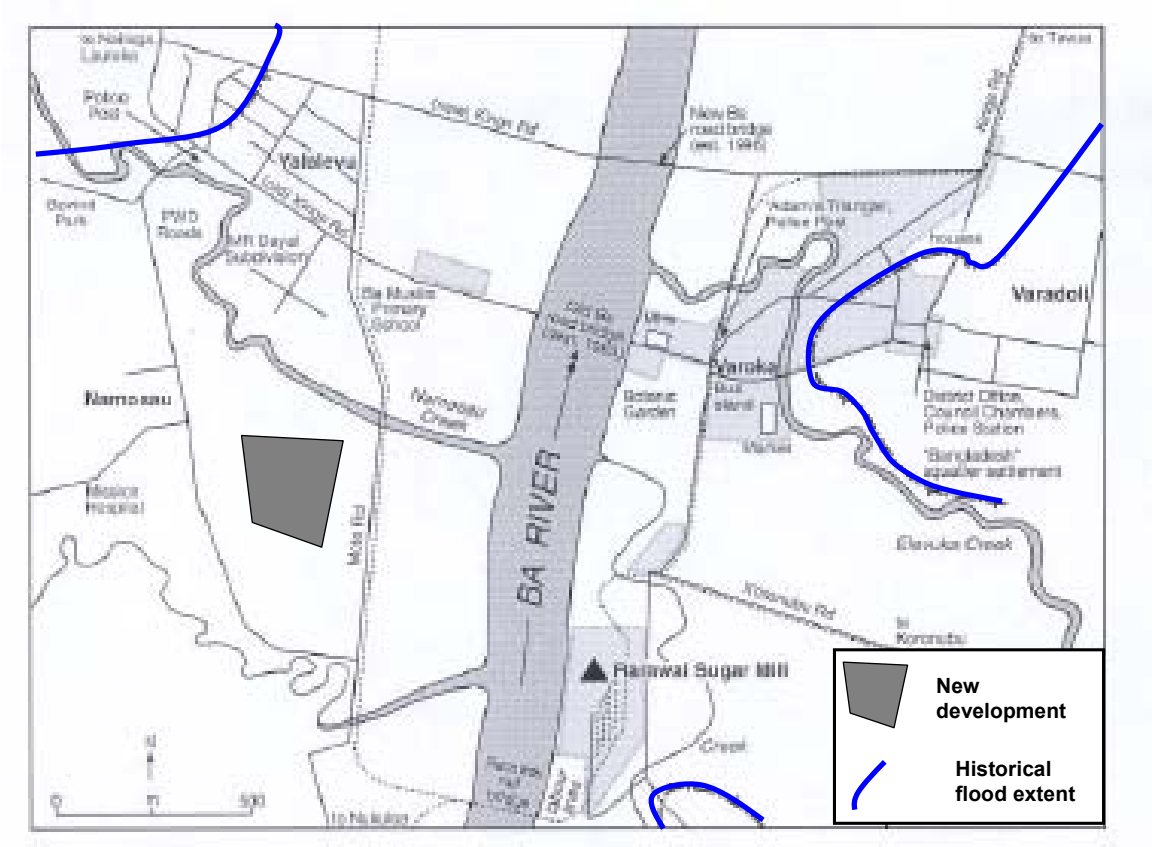


Figure 2 Map of Ba town

Case 2 Barrage on the River Sarawak at Kuching in Malaysia

A new barrage is proposed for the River Sarawak about 2 km downstream of the city of Kuching in Malaysia in order to remove tidal effects from the river in the centre of the city. The project is part of an urban regeneration programme. A study is needed to assess the impact of the proposed barrage on flooding in the city, and optimise the hydraulic design.

The site is about 5 km from the sea, where the tide range is 5 metres. The existing tidal limit is upstream is 20 km upstream from the mouth of the River Sarawak.

The design flood flow for the barrage is about 2490 m^3/s. This has a return period of 1 in 200 years. There is one calibration point for the largest recent flood that occurred in 1987 and had a flow of about 1590 m^3/s. Better data exists for observed floods with flows up to 1100 m^3/s.

The following drawings and photographs are attached:

Figure 3 General location map for the River Sarawak
Figure 4 Photograph of the river upstream of the barrier site
Figure 5 Photograph of a barrier similar to that which is propose

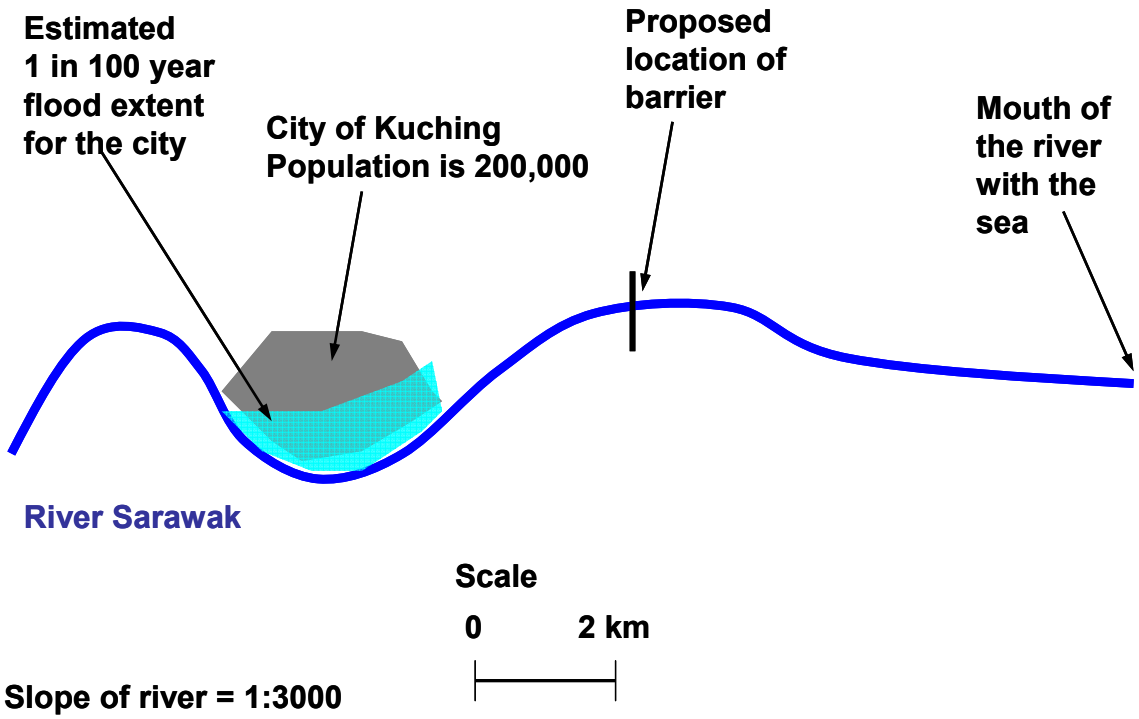


Figure 3 General location map for the River Sarawak

Figure 4 Photograph of the river upstream of the barrier site

Figure 6 Picture of a barrier similar to that which is proposed

Case 3 Proposed bypass channel for the city of Brechin in New Zealand

A bypass channel is proposed on a river in New Zealand to reduce flooding in the city of Brechin. The location of the bypass channel is shown in Figure 7. The local government requires that there should be no increase in flood levels. The river has a slope of 1 in 1,000. A study was needed to assess the impact of the proposed design on flood levels, and develop a scheme which will not raise flood levels. The bankfull capacity of the river channel through Brechin has been estimated to be 200 m^3/s.

Calibration data were available for an event which occurred in 1991 which had a flow of 550 m^3/s and an approximate return period of 1 in 100 years.

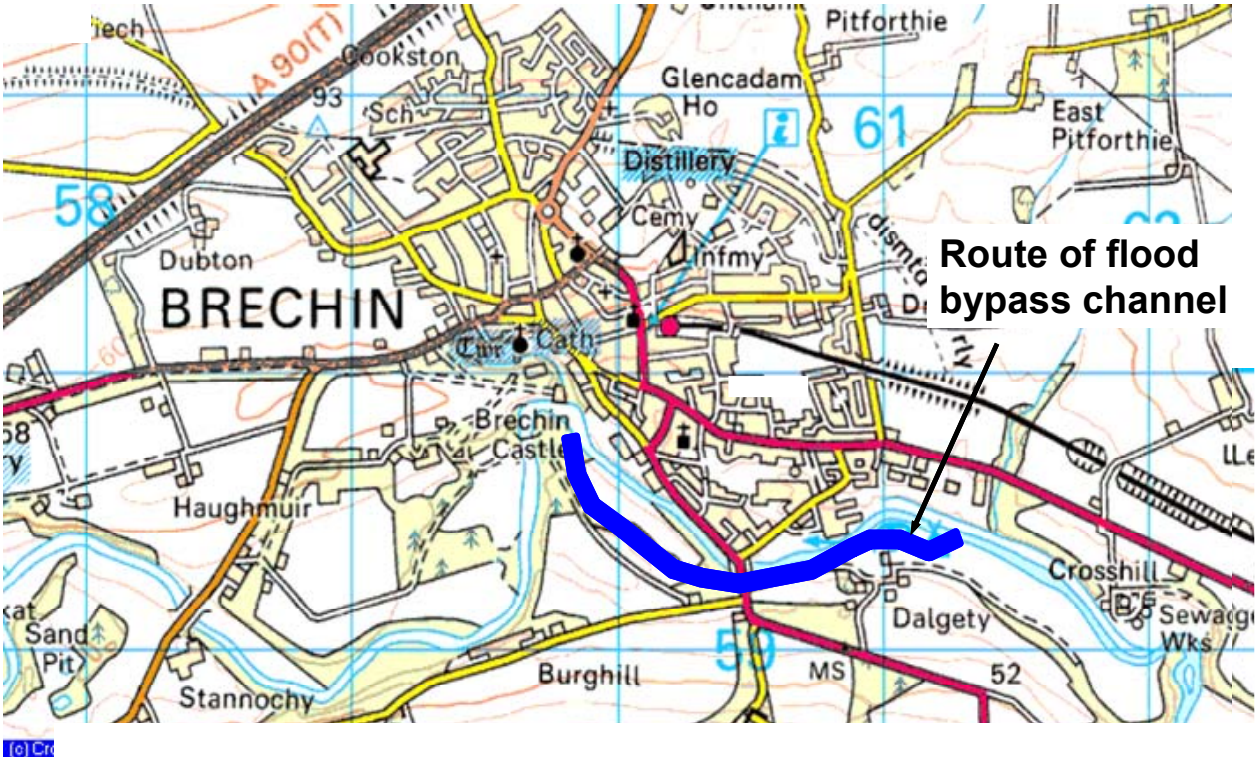


Figure 7 Location plan for the city of Brechin and the proposed bypass channel

River resistance and roughness

Learning objectives

To know why it is important to estimate river roughness and resistance

To understand the effect of different bed materials, vegetation types and other river characteristics on roughness

Skills acquired

To be able to estimate the roughness values for different types of rivers and floodplains using at least two different techniques

Why river resistance?

Channel resistance is the opposing force to the pressure imbalance which effects fluid flow

Quantifying resistance is essential in determining water levels

Greater resistance results in lower velocities and higher water levels

What comprises resistance?

Resistance arises from:

- Bed surface material

- Channel alignment and sinuosity

What comprises resistance?

Resistance arises from:

- Channel irregularity

What comprises resistance?

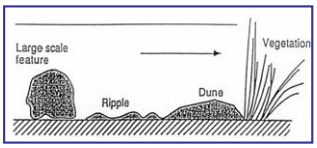
Resistance arises from:

- Channel shape
- Altitude or gradient
- Vegetation and sediments

What is roughness?

Roughness is only one component of channel resistance

It results from boundary friction:



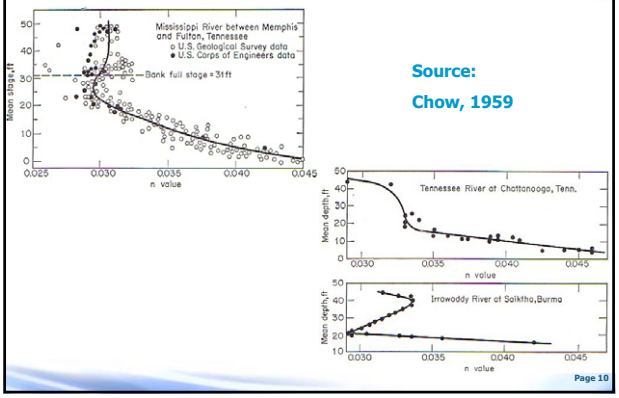
It should not be confused with overall resistance

What is a roughness coefficient?

Historically, this typically represents a *resistance* coefficient:

- A number which describes the resistance of the channel to flow
- Depends upon the resistance equation being used e.g. Chezy, Manning, Colebrook-White
- It varies with depth of flow

Variation of n with depth


Mississippi River between Memphis and Fulton, Tennessee
o U.S. Geological Survey data
• U.S. Corps of Engineers data
Bank full stage = 31ft
Mean stage, ft
n value
Tennessee River at Chattanooga, Tenn.
Irrawaddy River at Sakitha, Burma
Mean depth, ft

Source:

Chow, 1959

Calculating roughness

1. Measurement of channel section, discharge, water level, slope and use Manning's equation
2. Photographic method
3. Tabular method giving a range of values for different situations
4. Cowan's or Soil Conservation Service method
5. Experience

1. Use Manning equation

$$Q = \frac{AR^{2/3}s^{1/2}}{n} \quad \Rightarrow \quad n = \frac{AR^{2/3}s^{1/2}}{Q}$$

Q:	Flow	(m^3/s)
A:	Cross-sectional area	(m^2)
R:	Hydraulic radius (A/P)	(m/m)
P:	Wetted perimeter	(m)
s:	Water surface slope	(m/m)
n:	Manning's roughness coefficient	

Other available equations

Chezy equation (1768) - resistance represented by Chezy's C

$$V = C\sqrt{Rs}$$

Colebrook-White equation (1937) - resistance represented by Darcy f friction factor

$$\frac{1}{\sqrt{f}} = -c\log\left[\frac{k_s}{aR} + \frac{b}{\mathrm{Re}\sqrt{f}}\right]$$

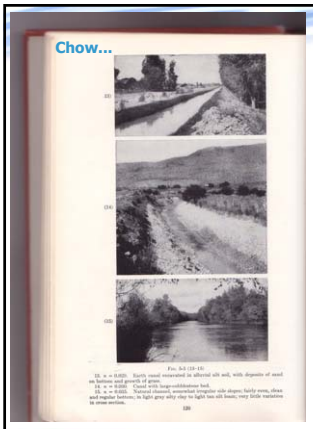
2. Photographic method

Available texts:

- **Chow** V.T., 1959, Open Channel Hydraulics, McGraw-Hill Book Company, US.
- **Barnes** H.H., 1967, Roughness Characteristics of Natural Channels, US Geological Survey, Water-Supply Paper No. 1849, pp214, Washington DC.
- **Hicks** D.M. **& Mason** P.D., 1998, Roughness Characteristics of New Zealand Rivers, NIWA, Christchurch, 329pp.
- **Yen** B. C., 1991, Channel Flow Resistance: Centennial of Manning's Formula, Water Resources Publications, LLC.

Photographic advice

Chow...



Hicks & Mason...

View from top cross-section looking downstream.

View of bottom cross-section looking upstream.

3. Tabular advice in Chow (1959)

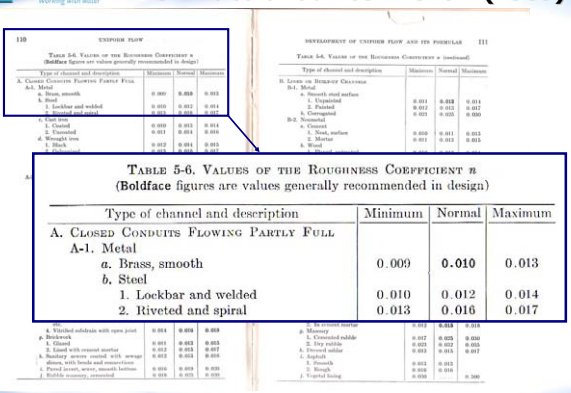


TABLE 5-6. VALUES OF THE ROUGHNESS COEFFICIENT *n*
(**Boldface** figures are values generally recommended in design)

Type of channel and description	Minimum	Normal	Maximum
A. CLOSED CONDUITS FLOWING PARTLY FULL			
A-1. Metal			
a. Brass, smooth	0.009	**0.010**	0.013
b. Steel			
1. Lockbar and welded	0.010	0.012	0.014
2. Riveted and spiral	0.013	0.016	0.017

4. Cowans (1956) method

Select a basic Manning's n value, n_b

Adjust basic value for effects of :

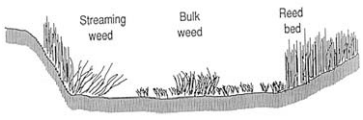
- shape and size of channel cross-section (n_s)
- obstructions (n_o)
- vegetation (n_v)
- surface irregularites (n_c) and
- meandering of channel (m_s)

Determine overall roughness value n from:

$$n = m_s(n_b + n_s + n_o + n_v + n_c)$$

What about vegetation?

Vegetation increases the channel roughness

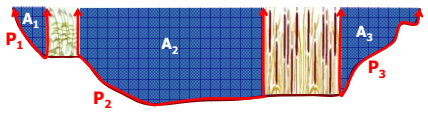


We can calculate increased roughness due to vegetation and determine the impact on the water level

What is the effect of vegetation?

Blockage to flow area - flow restricted to part of section

Increases the effective wetted perimeter



US Soil Conservation Service Estimation of Manning's n

Base value n_b

Channel character	n_b
Channels in earth	0.02
Channels in fine gravel	0.024
Channels cut into rock	0.025
Channels in coarse gravel	0.028

Addition n_s for streamwise variation

Character of variations in size and shape of cross sections	n_s
Changes in size or shape occurring gradually	0.000
Large and small sections alternating occasionally or shape changes causing occasional shifting of main flow from side to side	0.005
Large and small sections alternating frequently or shape changes causing frequent shifting of main flow from side to side	0.010 to 0.015

Addition n_o for obstructions in the watercourse

Character of obstructions	n_o
Negligible	0.000
Minor	0.010 to 0.015
Appreciable	0.020 to 0.030
Severe	0.040 to 0.060

Obstructions may include debris deposits, exposed roots, fallen trees, boulders, rocks etc. In assessing their effect the following factors should be considered - reduction in flow area at various depths, angularity of the obstructions, position and spacing of the obstructions.

Addition n_v for vegetation

Low influence **n_v = 0.005 to 0.010**

Dense growths of flexible turf grasses or weeds, of which Bermuda grass and blue grass are examples, where the average depth of flow is 2 to 3 times the height of vegetation. Supple seedling tree switches such as willow, cottonwood, or salt cedar where the average depth of flow is 3 to 4 times the height of the vegetation.

Moderate influence **n_v = 0.010 to 0.025**

Brushy growths, moderately dense, similar to willows 1 to 2 years old, dormant season, along side slopes of channel with no significant vegetation along the channel bottom, where the hydraulic radius is greater than 2 ft (0.6m). Turf grasses where the average depth of flow is 1 to 2 times the height of vegetation. Stemmy grasses, weeds, or tree seedlings with moderate cover where the average depth of flow is 2 to 3 times the height of vegetation.

High influence	**n_v = 0.025 to 0.050**

Dormant season, willow or cottonwood trees 8 to 10 years old, intergrown with some weeds and brush, none of the vegetation in foliage, where the hydraulic radius is greater than 2 ft (0.6m).

Growing season, bushy willows about 1 year old intergrown with some weeds in full foliage along side slopes, no significant vegetation along channel bottom, where hydraulic radius is greater than 2 ft (0.6m).

Very high influence	**n_v = 0.050 to 0.100**

Turf grasses where the average depth of flow is less than one half the height of vegetation.

Growing season, trees intergrown with weeds and brush, all in full foliage; any value of hydraulic radius up to 10 or 15 ft (3 to 4.6m).

Growing season, bushy willows about 1 year old, intergrown with weeds in full foliage along side slopes; dense growth of cat tails along channel bottom; any value of hydraulic radius up to 10 or 15 ft (3 to 4.6m).

Addition n_c for channel condition

Degree of irregularity	Surfaces comparable with	n_c
Smooth	The best obtainable for the materials involved	0.000
Minor	Good dredged channels; slightly eroded or scoured side slopes of canals or drainage channels.	0.005
Moderate	Fair to poor dredged channels; moderately sloughed or eroded side slopes of canals or drainage channels.	0.010
Severe	Badly sloughed banks of natural channels; badly eroded or sloughed sides of canals or drainage channels; unshaped, jagged, and irregular surfaces of channels excavated in rock.	0.020

Multiplier m_s for sinuosity

(As proposed by C S James)

m_s	=	1.0	s = 1
m_s	=	0.57 + 0.43s	1 < s < 1.7
m_s	=	1.30	s > 1.7

Final Calculation of Manning's n

$$n = m_s (n_b + n_s + n_o + n_v + n_c)$$

Manning's n roughness

Reference: Chow 1959.

		Min	Norm	Max
A	**Closed Conduits flowing partly full**			
A-1	**Metals**			
	a) Brass, smooth	0.009	0.01	0.013
	b) Steel			
	Lockbar and welded	0.01	0.012	0.014
	Riveted and spiral	0.013	0.016	0.017
	c) Cast iron			
	Coated	0.01	0.013	0.014
	Uncoated	0.011	0.014	0.016
	d) Wrought iron			
	Black	0.012	0.014	0.015
	Galvanized	0.013	0.016	0.017
	e) Corrugated metal			
	subdrain	0.017	0.019	0.021
	storm drain	0.021	0.024	0.03
A-2	**Non-Metals**			
	a) Lucite	0.008	0.009	0.01
	b) Glass	0.009	0.01	0.013
	c) Cement			
	Neat surface	0.01	0.011	0.013
	Mortar	0.011	0.013	0.015
	d) Concrete			
	Culvert, straight and free of debris	0.01	0.011	0.013
	Culvert with bends, connections and some debris	0.011	0.013	0.014
	Finished	0.011	0.012	0.014
	Sewer with manholes	0.013	0.015	0.017
	Unfinished, steel form	0.012	0.013	0.014
	Unfinished, smooth wood form	0.012	0.014	0.016
	Unfinished, rough wood form	0.015	0.017	0.02
	e) Wood			
	Stave	0.01	0.012	0.014
	Laminated, treated	0.015	0.017	0.02
	f) Clay			
	Common drainage tile	0.011	0.013	0.017
	Vitrified sewer	0.011	0.014	0.017
	Vitrified sewer with manholes	0.013	0.015	0.017
	Vitrified subdrain with open jnt	0.014	0.016	0.018
	g) Brickwork			
	Glazed	0.011	0.013	0.015
	Lined with cement mortar	0.012	0.015	0.017
	h) Sanitary sewers coated with sewage slimes with bends and connections	0.012	0.013	0.016
	i) Paved invert, sewer, smooth bottom	0.016	0.019	0.02
	j) Rubble masonry	0.018	0.025	0.03

B Lined or built-up channels			
B-1 Metal	Min	Norm	Max
a) Smooth steel surface			
Unpainted	0.011	0.012	0.014
Painted	0.012	0.013	0.017
b) Corrugated	0.021	0.025	0.03
B-2 Nonmetal			
a) Cement			
Neat, surface	0.01	0.011	0.013
Mortar	0.011	0.013	0.015
b) Wood			
Planed, untreated	0.01	0.012	0.014
Planed, creosoted	0.011	0.012	0.015
Unplaned	0.011	0.013	0.015
Plank with battens	0.012	0.015	0.018
Lined with roofing paper	0.01	0.014	0.017
c) Concrete			
Trowel finish	0.011	0.013	0.015
Float finish	0.013	0.015	0.016
Finished with gravel on bottom	0.015	0.017	0.02
Unfinished	0.014	0.017	0.02
Gunite, good section	0.016	0.019	0.023
Gunite, wavy section	0.018	0.022	0.025
On good excavated rock	0.017	0.02	
On irregular excavated rock	0.022	0.027	
d) Concrete bottom float finished with sides of			
dressed stone in mortar	0.015	0.017	0.02
random stone in mortar	0.017	0.02	0.024
cement rubble masonary, plastered	0.016	0.02	0.024
cement rubble masonary	0.02	0.025	0.03
dry rubble or riprap	0.02	0.03	0.035
e) Gravel bottom with sides of			
formed concrete	0.017	0.02	0.025
random stone in mortar	0.02	0.023	0.026
dry rubble or riprap	0.023	0.033	0.036
f) Brick			
Glazed	0.011	0.013	0.015
In cement mortar	0.012	0.015	0.018
g) Masonary			
Cemented rubble	0.017	0.025	0.03
Dry rubble	0.023	0.032	0.035
h) Dresses ashlar	0.013	0.015	0.017
i) Asphalt			
smooth	0.013	0.013	
rough	0.016	0.016	
j) vegetal lining	0.03		0.5
C Excavated or dredged			
a) Earth, straight and uniform			
Clean, recently completed	0.016	0.018	0.02
Clean after weathering	0.018	0.022	0.025
Gravel, uniform section, clean	0.022	0.025	0.03
With short grass, few weeds	0.022	0.027	0.033

b) Earth, winding and sluggish			
No vegetation	0.023	0.025	0.03
Grass, some weeds	0.025	0.03	0.033
Dense weeds or aquatic plants in deep channel	0.03	0.035	0.04
Earth bottom and rubble sides	0.028	0.03	0.035
Stony bottom and weedy banks	0.025	0.035	0.04
Cobble bottom and clean sides	0.03	0.04	0.05
c) Dragline-excavated or dredged			
No vegetation	0.025	0.035	0.033
Light brush on banks	0.035	0.05	0.06
d) Rock cuts			
Smooth and uniform	0.025	0.035	0.04
Jagged and irregular	0.035	0.04	0.05
e) Channels not maintained, weeds and brush uncut			
Dense weeds, high as flow depth	0.05	0.08	0.12
Clean bottom, brush on sides	0.04	0.05	0.08
Same, highest stage of flow	0.045	0.07	0.11
Dense brush, high stage	0.08	0.1	0.14

D Natural streams

D-1 Minor streams (top width at flood stage < 100 ft)

		Min	Norm	Max
(a)	Streams on plain			
	1 Clean, straight, full stage, no rifts or deep pools	0.025	0.030	0.033
	2 Same as above, but more stones and weeds	0.030	0.035	0.040
	3 Clean, winding, some pools and shoals	0.033	0.040	0.045
	4 Same as above, but some weeds and stones	0.035	0.045	0.050
	5 Same as above, lower stages, more ineffective slopes and sections	0.040	0.048	0.055
	6 Same as 4, but more stones	0.045	0.050	0.060
	7 Sluggish reaches, weedy, deep pools	0.050	0.070	0.080
	8 Very weedy reaches,deep pools, or floodways with heavy stand of timber and underbrush	0.075	0.100	0.150
(b)	Mountain streams, no vegetation in channel, banks usually steep, trees and brush along banks submerged at high stages			
	1 Bottom : gravels, cobbles, and few boulders	0.030	0.040	0.050
	2 Bottom : cobbles with large boulders	0.040	0.050	0.070

D-2 Flood plains

		Min	Norm	Max
(a)	Pasture, no brush			
	1 Short grass	0.025	0.030	0.035
	2 High grass	0.030	0.035	0.050
(b)	Cultivated areas			
	1 No crop	0.020	0.030	0.040
	2 Mature row crop	0.025	0.035	0.045
	3 Mature field crops	0.030	0.040	0.050
(c)	Brush			
	1 Scattered brush, heavy weeds	0.035	0.050	0.070
	2 Light brush and trees, in winter	0.035	0.050	0.060
	3 Light brush and trees, in summer	0.040	0.060	0.080
	4 Medium to dense brush, in winter	0.045	0.070	0.110
	5 Medium to dense brush, in summer	0.070	0.100	0.160
(d)	Trees			
	1 Dense willows, summer, straight	0.110	0.150	0.200
	2 Cleared land with tree stumps, no sprouts	0.030	0.040	0.050
	3 Same as above, but with heavy growth of sprouts	0.050	0.060	0.080
	4 Heavy stand of timber, a few down trees, little undergrowth, flood stage below branches	0.080	0.100	0.120
	5 Same as above, but with flood stage reaching branches	0.100	0.120	0.160

D-3 Major streams (top width at flood stage > 100 ft). The n value is less than that for minor streams of similar description, because banks offer less effective resistance

		Min	Norm	Max
(a)	Regular section with no boulders or brush	0.025	-	0.060
(b)	Irregular and rough section	0.035	-	0.100

Exercise

Estimation of roughness

Information

Eight photos of different rivers in the UK are attached. For each river there is also a plan form, cross-section shapes, details of slope, discharge, some cross-section information and a short description of the channel

Task

Based on the pictorial and section information given make an estimate of the roughness of each river reach. Three steps:

1. Chow Tables - find an n
2. Use Cowan's approach - determine an n
3. Given the flow rate - back calculate 'n' and compare to answers 1 and 2

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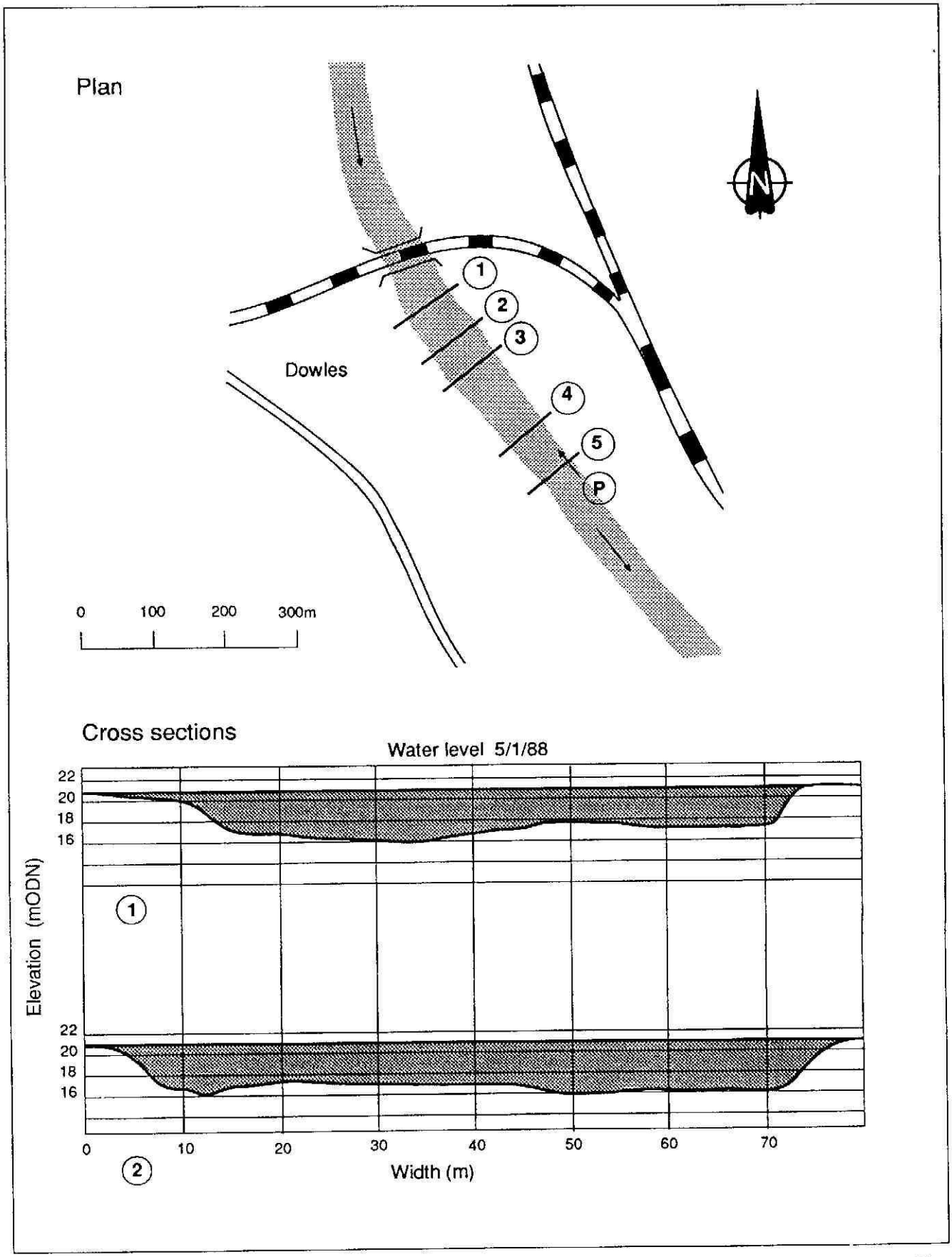
Flow rates for part 3

River Severn, Bewdley	358.0 m^3/s
Chatsworth	94.5 m^3/s
Drakelow	169.0 m^3/s
Avon	110.0 m^3/s
Moniflod	52.8 m^3/s
Tanat	54.8 m^3/s
Vyrnwy	167.7 m^3/s
Severn, Montford	151.0 m^3/s



PH/1/12-95/ f.fine

Plan and cross sections, River Severn at Bewdley

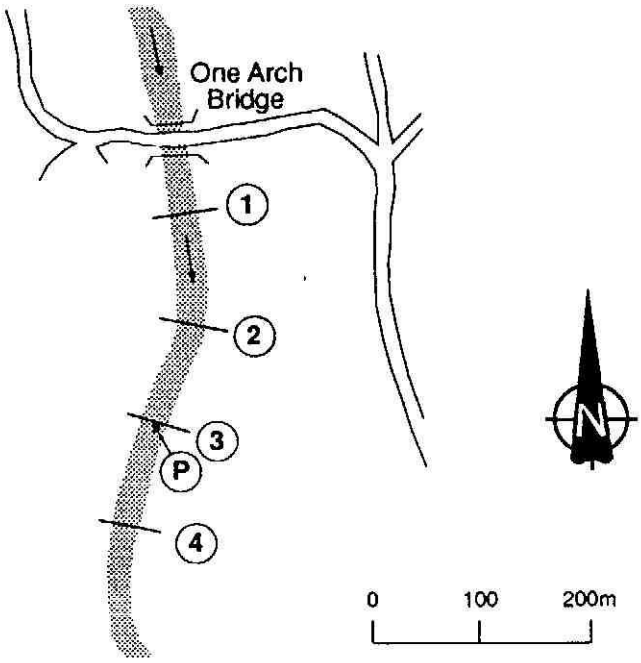
n =

Bankfull hydraulic and geometric characteristics		5/1/88
Manning's n roughness coefficient	=	
Discharge	=	
Water surface slope	=	0.000203 (1:4926)
Average cross sectional area	=	249 m^2
Average flow width	=	78m (information available for xs 1 and 2)
Average hydraulic radius	=	3.24 m

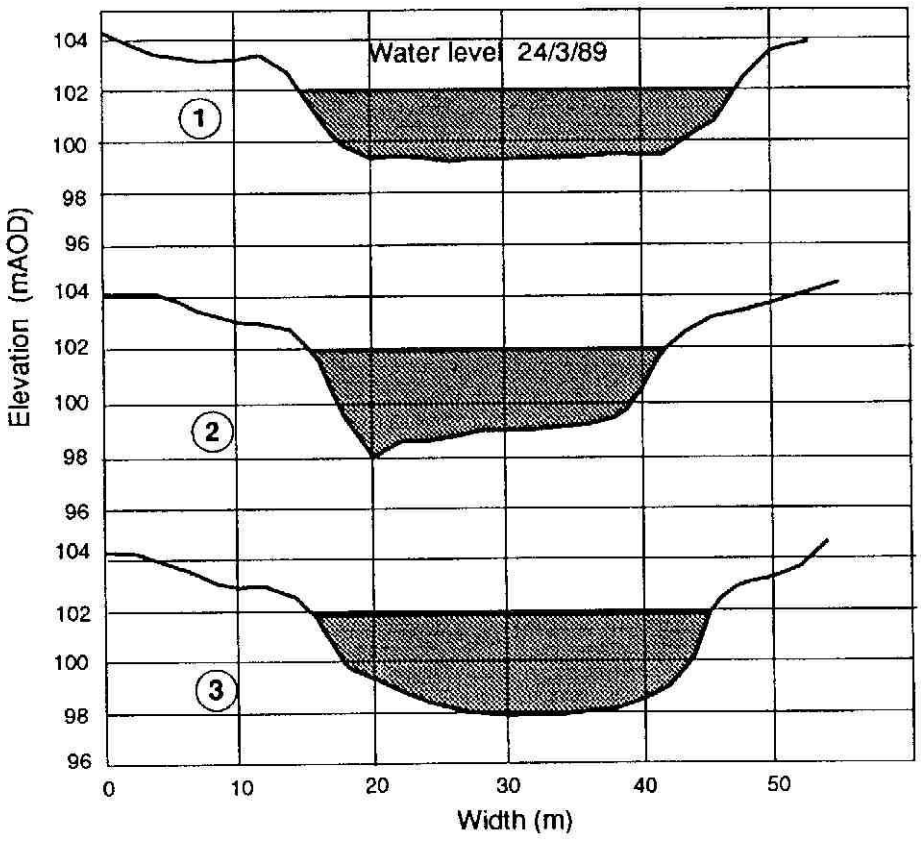
Description of channel

Bed material gravel at upstream end, otherwise unknown. Banks grass with scattered willow, alder and hawthorn trees; undergrowth of nettle and brambles. Left and right flood plains are short grass pasture.

Plan



Cross sections



PH/8/12-95/ f.line

Plan and cross sections, River Derwent at Chatsworth

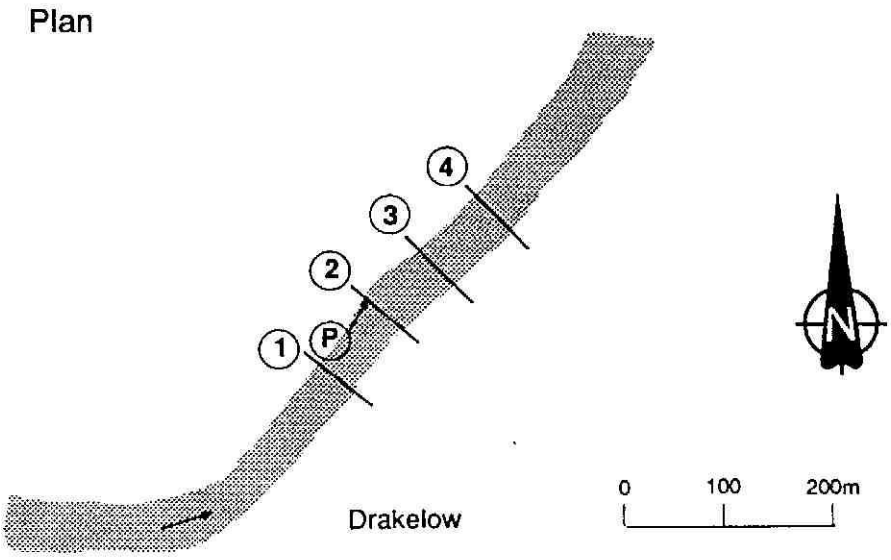
n =

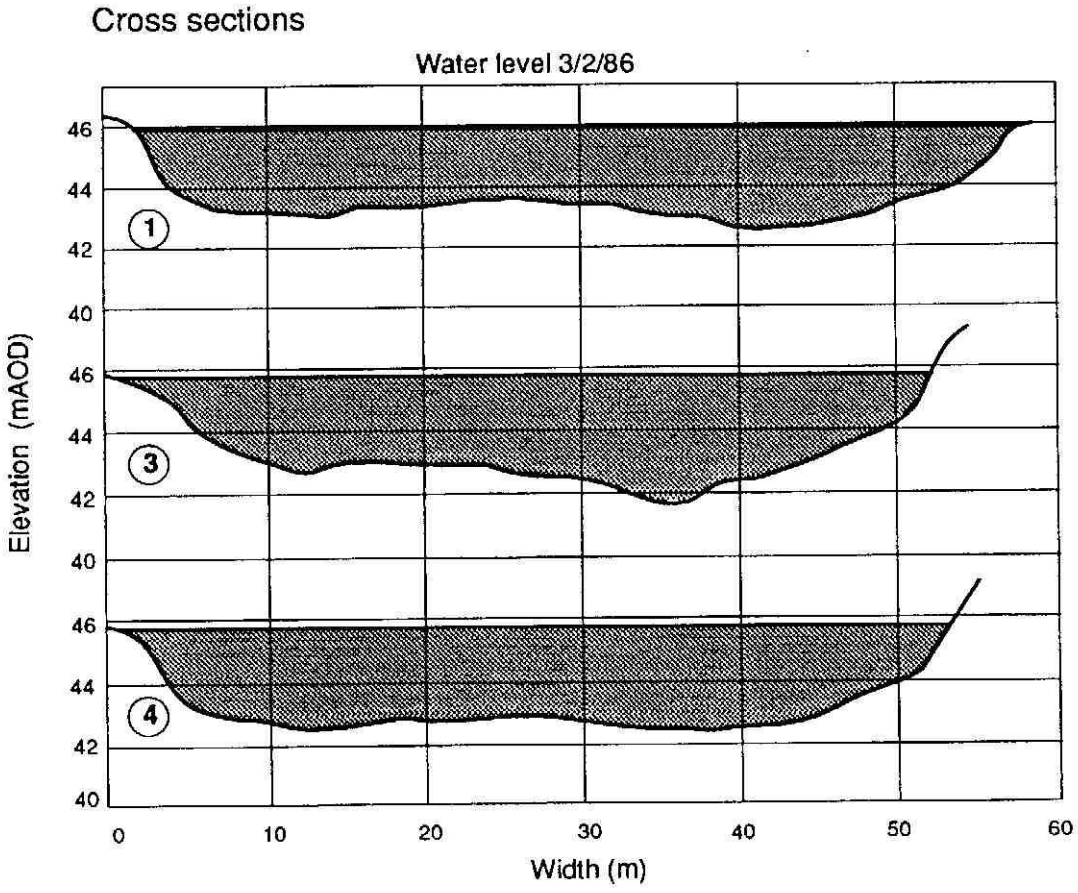
Bankfull hydraulic and geometric characteristics 24/3/89

Manning's n roughness coefficient	=	
Discharge	=	
Water surface slope	=	0.000695 (1:1439)
Average cross sectional area	=	77.59 m^2
Average flow width	=	29 m
Average hydraulic radius	=	2.42 m

Description of channel

Bed material gravel with shallow rock step. Banks grass with mature alder, sycamore and ash trees. Left and right flood plains are short grass pasture.





PH/6/12-95/ f.line

Plan and cross sections, River Trent at Drakelow

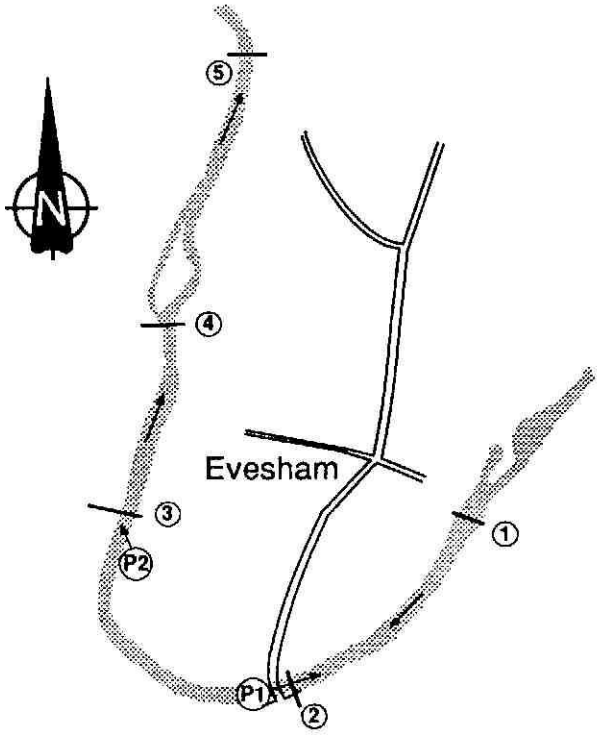
n =

Bankfull hydraulic and geometric characteristics 3/2/86

Manning's n roughness coefficient	=	
Discharge	=	
Water surface slope	=	0.000437 (1:2288)
Average cross sectional area	=	142.5 m^2
Average flow width	=	54 m
Average hydraulic radius	=	2.62 m

Description of channel

Bed material unknown. Left bank grass with horse chestnut trees at downstream limit of reach. Right bank with horse chestnut and beech trees. Left flood plain is a golf course with occasional oak, yew, hawthorn, horse chestnut and poplar tree coppice. Right bank formed by steep wooded bank lowering to flood plain at downstream limit with beech and chestnut trees with bank grass undergrowth.



Plan

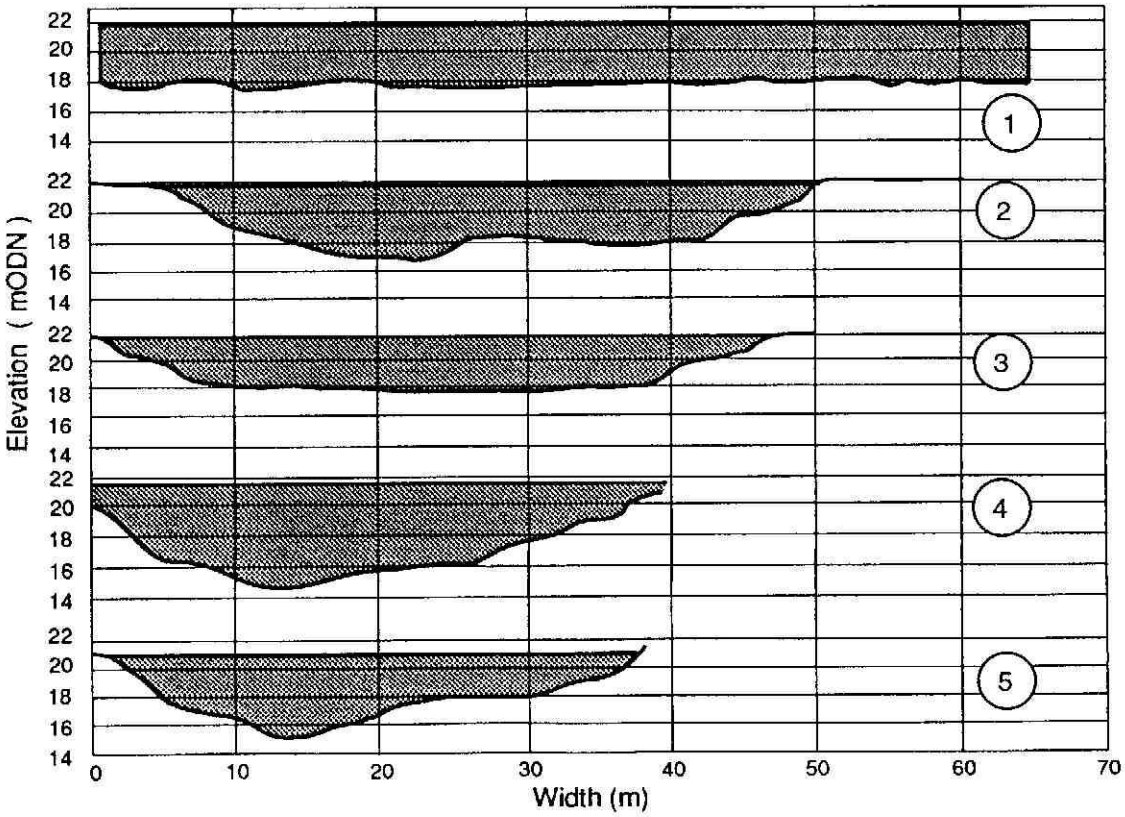
Description of channel

Meander. Bed material unknown. Bank lining variable; concrete wall, boat moorings, willow, hawthorne, ash, sycamore, holly, alder and horse chestnut with undergrowth of nettles and bramble.
Left flood plain parkland with mature elm trees, gardens with fences, rough pasture.
Right flood plain is parkland with mature elms and limes, market gardening.

0 400 800m

Water level 30/1/86

Cross sections



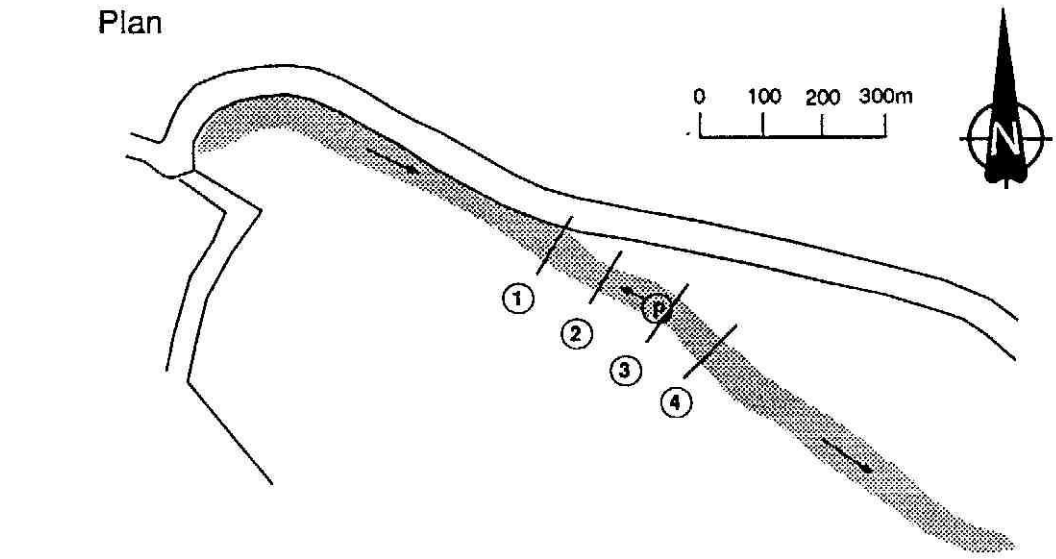
PH/4/12-95/ f.line

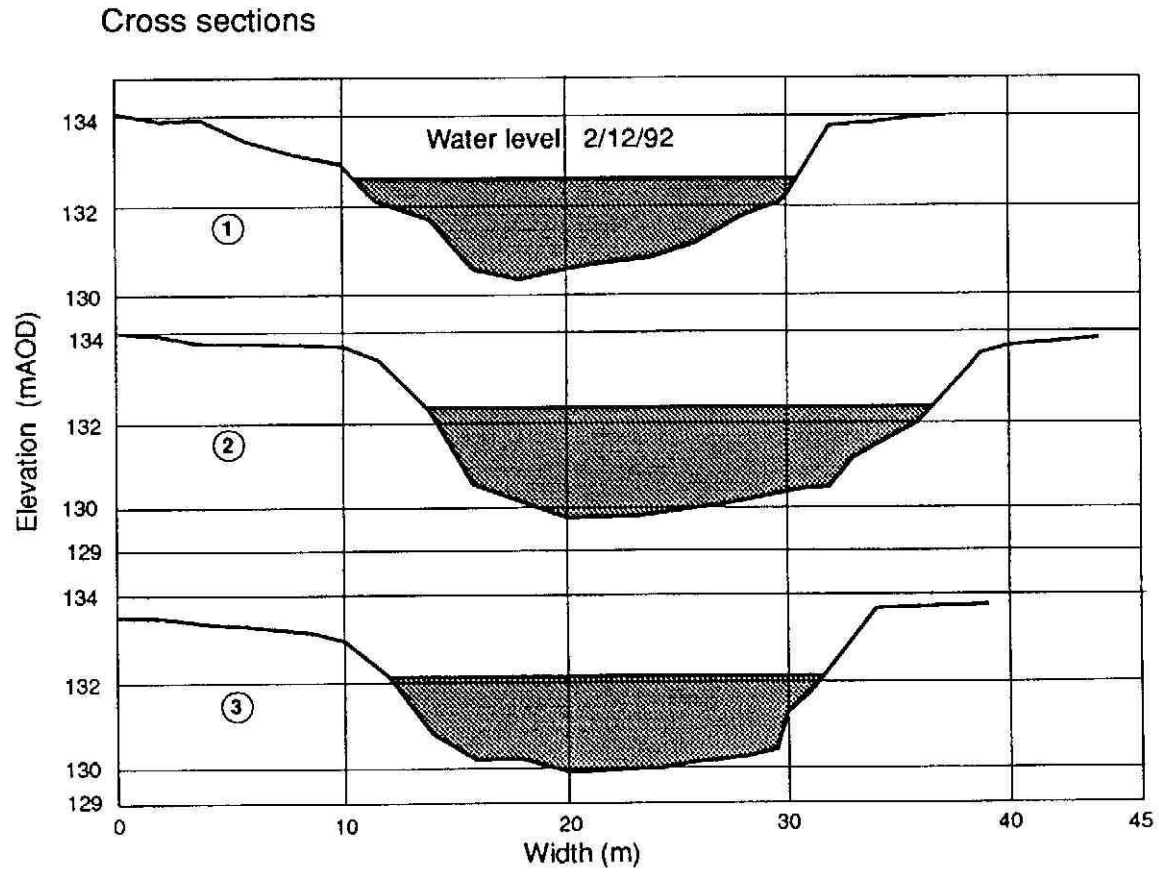
Plan and cross sections, River Avon at Evesham

n =

Bankfull hydraulic and geometric characteristics		30/1/86
Manning's n roughness coefficient	=	
Discharge	=	
Water surface slope	=	0.000234 (1:4274)
Average cross sectional area	=	147.9 m^2
Average flow width	=	45 m
Average hydraulic radius	=	3.11 m

n =





PH/7/12-95/f.line

Plan and cross sections, River Manifold at Ilam

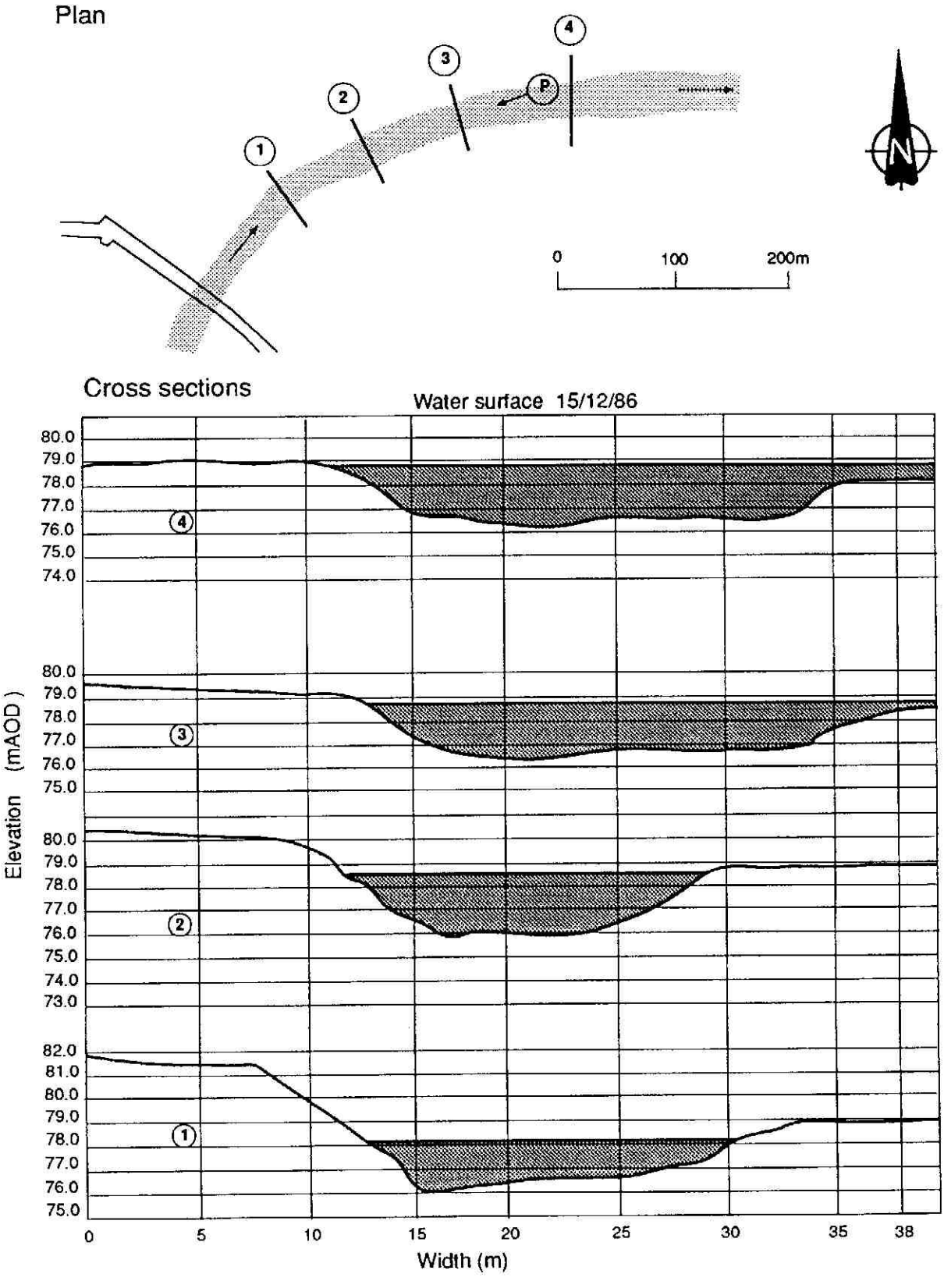
River Manifold at Ilam

Bankfull hydraulic and geometric characteristics 2/12/92 see Figure A3.6

Manning's n roughness coefficient	=	0.042
Discharge	=	$52.8m^3/s$
Water surface slope	=	0.001977 (1:506)
Average cross sectional area	=	$35.6m^2$
Average flow width	=	21m
Average hydraulic radius	=	1.64m

Description of channel

Bed material is gravel and boulders. Bank vegetation of alder, ash, hazel, beech, sycamore and hawthorn traces with grass, scattered undergrowth of bramble. Flood plains of short grass pasture with hedgerows and wire fencing.



PH/5/12-5/1.line

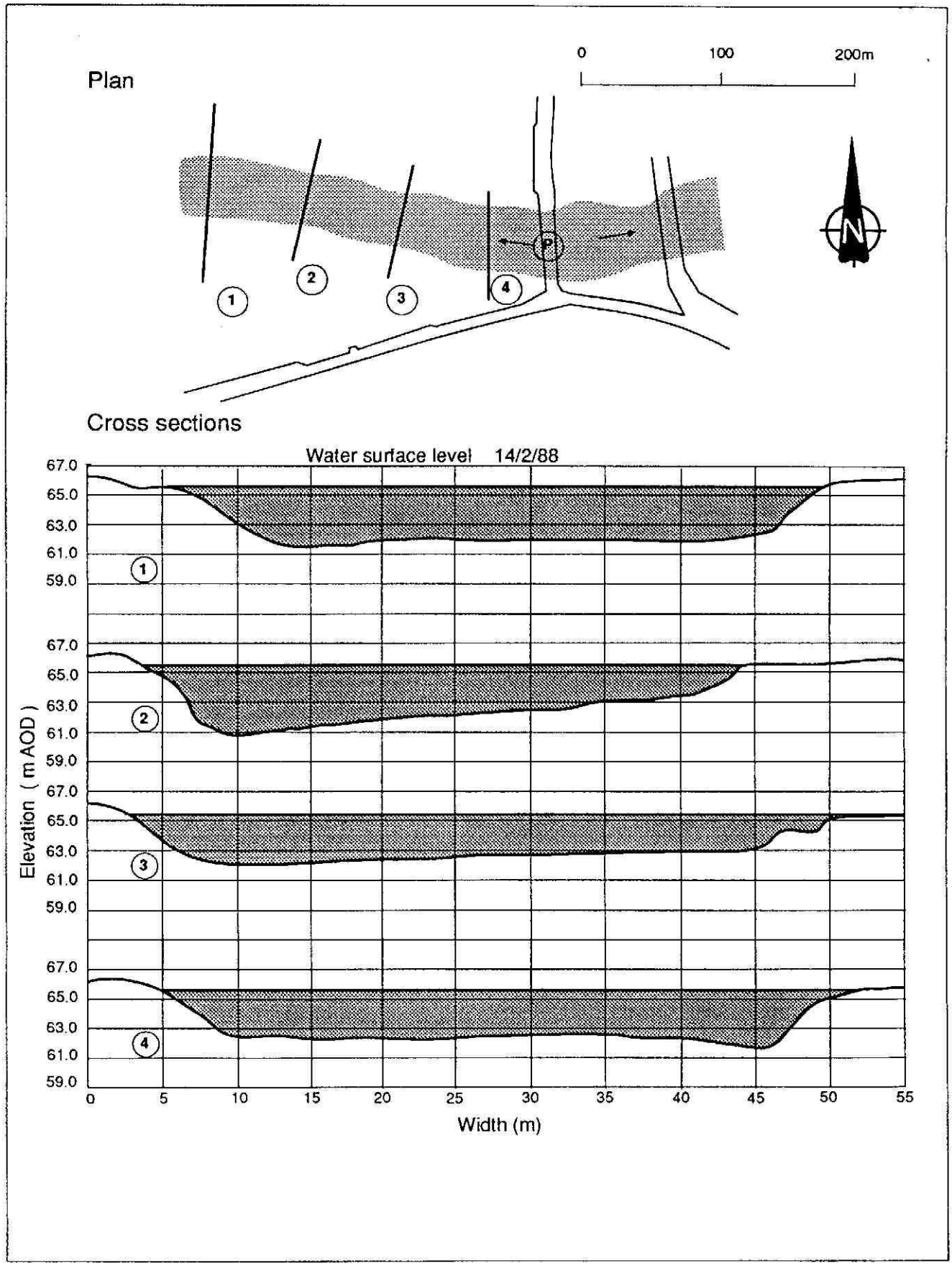
Plan and cross sections, River Tanat at Llanyblodwel

n =

Bankfull hydraulic and geometric characteristics		15/12/86
Manning's n roughness coefficient	=	
Discharge	=	
Water surface slope	=	0.000298 (1:336)
Average cross sectional area	=	40.4 m^2
Average flow width	=	26.7 m
Average hydraulic radius	=	1.45 m

Description of channel

Bed is gravel and boulders. Banks lined with mature alders, ash and willow, undergrowth of bramble, nettle, wild rose and rank grass. Left flood plain is sown with crops, right flood plain is short grass pasture. Field boundaries delimited by hedgerows.



PH/3/12-95/ f.line

Plan and cross section, River Vyrnwy at Llanymynech

n =

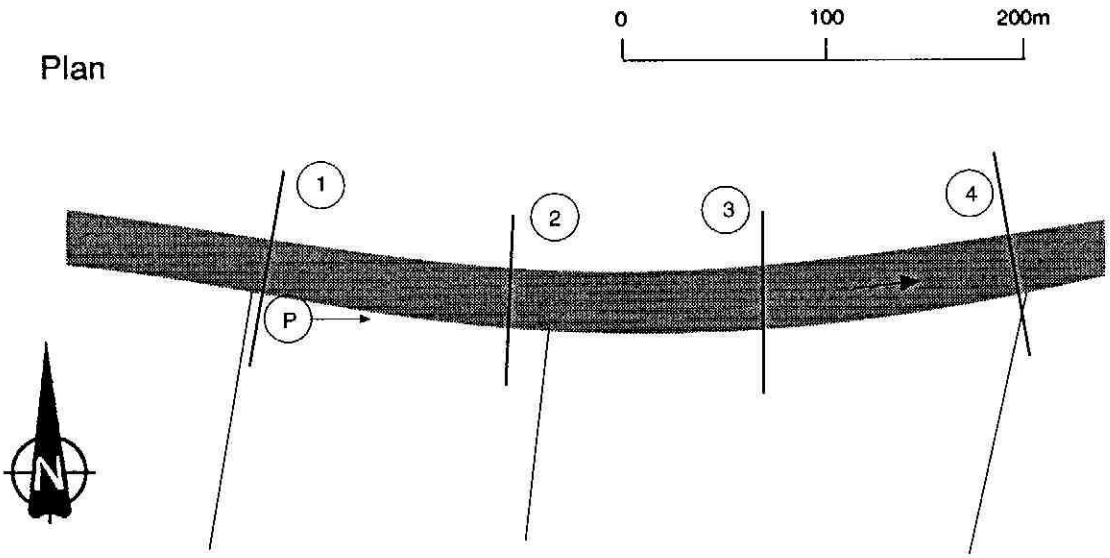
Bankfull hydraulic and geometric characteristics 14/2/88

Manning's n roughness coefficient	=	
Discharge	=	
Water surface slope	=	0.000372 (1:2688)
Average cross sectional area	=	131.6 m^2
Average flow width	=	46.4 m
Average hydraulic radius	=	2.25 m

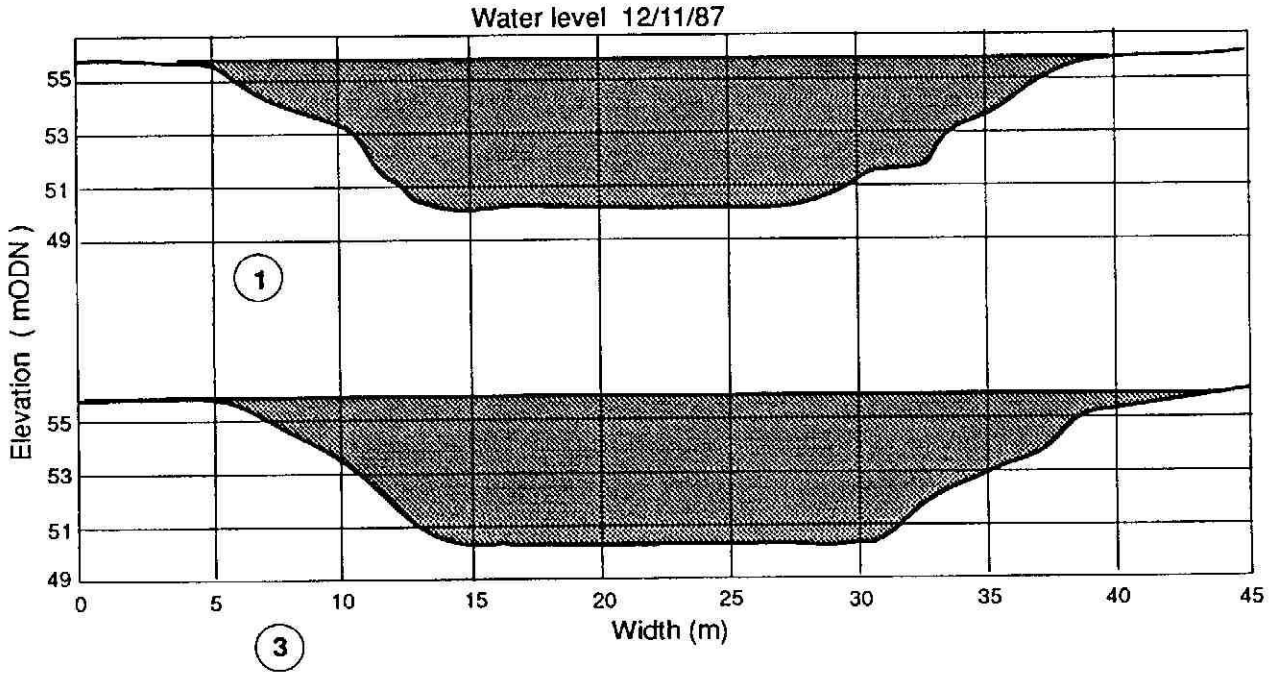
Description of channel

Bed material unknown. Right bank grass covered with scattered mature alders. Left bank lined with alder and willow. Left flood plain sown with crops, right flood plain is short grass pasture.

Plan



Cross sections



PH/2/12-95/ f.line

Plan and cross sections, River Severn at Montford

n =

Bankfull hydraulic and geometric characteristics		12/11/87
Manning's n roughness coefficient	=	
Discharge	=	
Water surface slope	=	0.000186 (1:5376)
Average cross sectional area	=	139 m^2
Average flow width	=	39.9 m
Average hydraulic radius	=	3.31 m

Description of channel

Bed material unknown. Left and right banks grass with occasional small willow trees. Flood plains of short grass pasture with hawthorn hedgerows and fences.

Floodplain mapping

Learning objectives

To know the uses of flood maps

To understand the limitations of certain types of flood maps

Skills acquired

To be able to distinguish between different types of river models

To know the data requirements to construct different types of flood maps

Floodplain mapping uses

Development control: Are proposed developments in the floodplain?

Flood warning: Which areas need flood warnings?

Where is the greatest risk (e.g. in terms of people being injured, buildings being damaged)

Insurance: What is insurance exposure/maximum probable loss?

Issues related to flood maps

Level of hazard

- The return period of design flood
- Extreme flood outline?

Flooding outside mapped flood limits

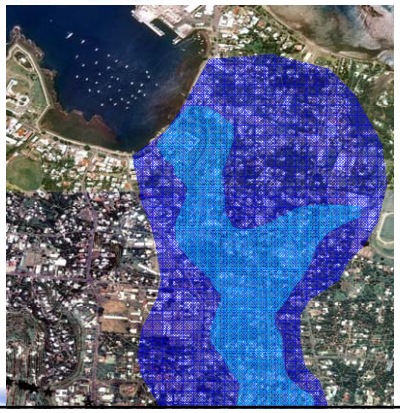
Uncertainty

Updating

Active flow areas

Storage areas

Example of a flood map



Methods for producing flood maps

Historical flood outlines

Flood levels plus topographic survey

- Direct flood levels (e.g. historical data)
- Predicted flood levels (e.g. modelling)

Historical flood outlines

What was the return period?

Extrapolate to required return period

Need to fill gaps in flood outlines

Use aerial and video photographs from recent floods

Use of satellite images

Account for changes since the flood occurred

Direct flood levels

Historical flood levels

- include old flood marks
- interpolate for required return period

Assess flood depth above bank level

Rating curve from surveyed cross sections

Predicted flood levels

- Range of methods and accuracy
- Rating curve from surveyed cross sections including gauging sites
- Hydrology and hydraulics
- Simple river models (e.g. typical section)
- Computational river models

Methods of map production

Hand-drawn outlines
- suitable for small areas

Cross section-derived
- quick
- adequate if no ground model

Ground model-derived using a GIS
- grid based
- Triangular Irregular Network (TIN) based

Cross-section derived maps

- Use real locations in river model
- Generate outline at peak of flood
- Add background or export to drawing package
- In some software packages simple animation can be carried out

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Ground model derived flood maps

Generate ground model

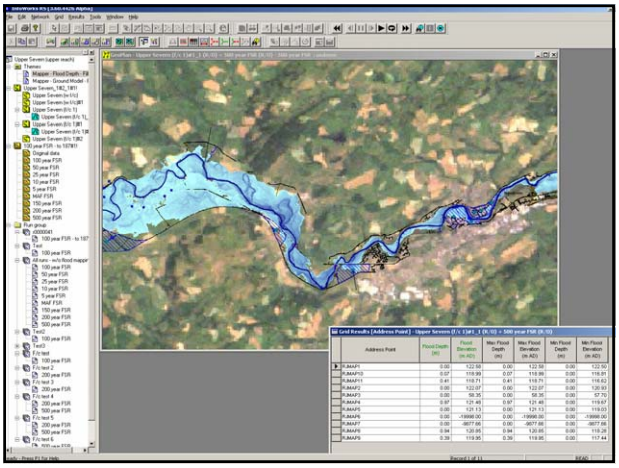
Export results from hydraulic model

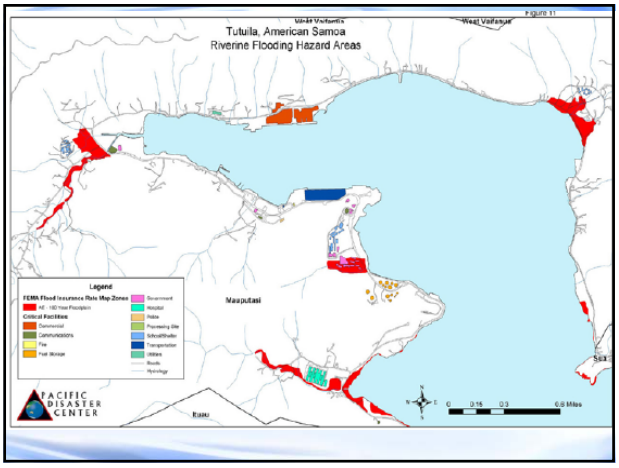
Use GIS (e.g. ArcView with 3D Analyst)

Ground-modelling representation

- Raster for simple floodplains
- TIN essential for embanked rivers

Output in ArcView, ArcGIS, AutoCAD etc





Day 4

Risk, uncertainty and error

Learning objective

To understand the difference between hazard and risk

To understand the difference between uncertainty and error

Skilled acquired

To be able to assess the uncertainty in river model results

To understand conceptual risk models used in flood management

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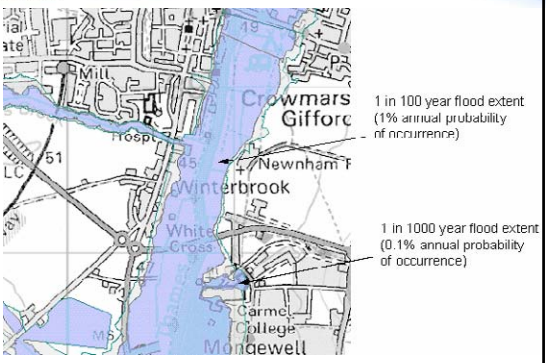
What is a hazard?

A hazard is a physical event, phenomenon or human activity with the *potential* to result in harm. A hazard does not necessarily lead to harm.

Example of a flood hazard map

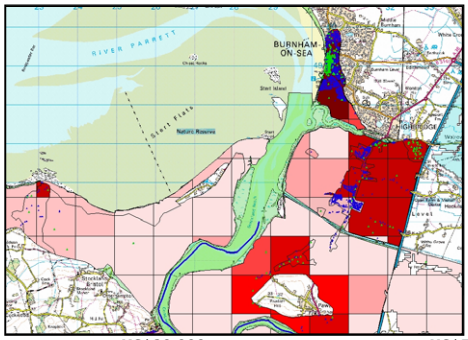


What is risk?

Risk in its simplest form has two components – the probability that an event will occur and the impact (or consequences) associated with that event.

Risk = Probability x Consequence

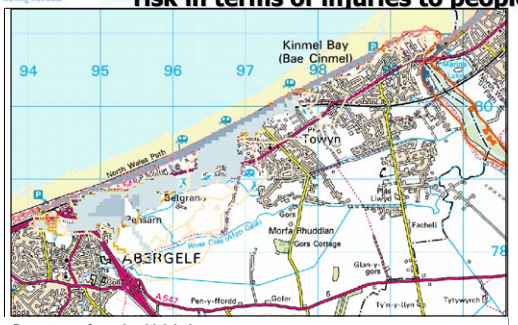
Example of a flood risk map showing risk in terms of economic damage



>US$20,000 | US$20,000 to US$15,000 | US$15,000 to US$5,000 | US$5,000 to US$1

Page 7

Example of a flood risk map showing risk in terms of injuries to people



Percentage of people with injuries

0% to 1% | 1% to 2.5% | 2.5% to 5% | 5% to 10% | 10% to 25% | 25% to 50%

Page 8

Conceptual risk model

Source:
Rainfall, river flow, storm surge

Pathway:
Bank failure, flood plain flow, sewer surcharging

Receptor:
Property, people, possessions, environment

Consequence:
Damages, distress, disease, death, degradation

Page 9

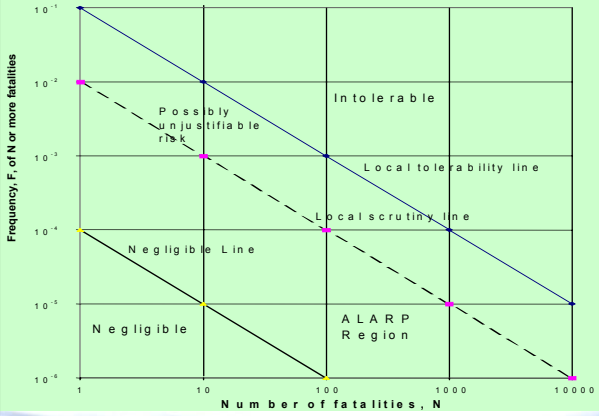
Acceptability of risk

Frequency F versus Impact curve N

- Frequency against impact (number of casualties)

Three categories of significance

- Acceptable/negligible
- Broadly acceptable/Possibly unjustifiable – As Low As Reasonably Practicable (ALARP)
- Unacceptable/intolerable



Perception of risk

Individual risk

- Element of choice and personal control over the hazard

Societal risk

- Imposed by others/nature
- No personal control on acceptance
- Aversion to high impact/ consequence events

Uncertainty

The components of uncertainty are:

- Natural variability
- Knowledge uncertainty
- Decision uncertainty

Natural variability

- Climate and weather
- Storm surge and waves
- Vegetation growth
- Spatial variability
- Channel geometry
- Blockages of structures

Characteristics of natural uncertainty

Cannot be controlled

New knowledge does not influence our ability to manage natural variability

Historical information may indicate the possible range of natural variability

Characteristics of knowledge uncertainty

Internal to our assessment methods

Can be reduced by improved knowledge, data, computer resource

Bounds of some contributions can be assessed (approximately)

Knowledge uncertainty - process model uncertainty

Process uncertainty

- Processes considered and their representation

Representation uncertainty

Data uncertainties

Parameter estimation

Calculation methods

Knowledge uncertainty - process model uncertainty

Process uncertainty

- Processes considered and their representation

Representation uncertainty

Data uncertainties

Parameter estimation

Calculation methods

Decision uncertainty

How do the options behave as conditions move away from the central estimate?

Influence of uncertainty estimates

Robustness and resilience of the design

Reversibility of the option

Adaptation for future change

Key components of uncertainty in practice

Hydrological design estimates

River roughness estimates

Inadequacies, inconsistencies, uncertainties in historical data

Structure blockage assumptions

Other components of uncertainty in practice

Uncertainties in formulae and calculations

Impact of climate change (e.g. sea level rise)

Trends and cycles (e.g. land tilt)

Changes in land use (e.g. urbanisation of the catchment)

Hydrological uncertainty

Arises from "statistical" uncertainty

Factor of about 2 on discharge for "no-data" equations

Possibly 20% uncertainty on 1 in 100 year flood flow with say 30 years data

Possibly best to use return period as "free parameter"

Quote a range e.g. 70 to 140 years instead of 100 years

River modelling accuracy

Hydrological Uncertainty

- usually the largest component

Flow to level correlation

- several factors from the modelling process

Level to flood limit correlation

- can be improved by better local survey

One dimensional river modelling accuracy

Survey uncertainties

Roughness uncertainty

Approximations in numerical methods

Calibration quality

Extrapolation above calibration flows

Uncertainty in river modelling

How to analyse the uncertainty in river modelling?

Assess the factors that contribute to the uncertainty

Survey accuracy

Model calibration

Resolution of the river model

Estimating uncertainty in 1-D river modelling

Numerical model resolution

- **Cross section spacing a key parameter**
- **Depends upon river regularity and slope**
  - ratio of areas between sections (2/3 to 3/2)
  - ratio of conveyance between sections (4/5 to 5/4)

Estimating uncertainty in 1-D river modelling

Model cross section spacing

Slope (1 in …)	Section Spacing (m)
300 to 1 000	75
1 000 to 3 000	200
3 000 to 10 000	500
10 000+	1000

Contribution to overall uncertainty less than 30 mm

Estimating uncertainty in 1-D river modelling

$E_{total} = \{(E_{tr})^2 + (E_c)^2 + (E_d)^2\}^{0.5}$

"E" is uncertainty in metres

E_{tr} = Topography and roughness uncertainty

E_c = Calibration uncertainty

E_d = Discretisation (i.e. section spacing) uncertainty

$E_{max} = 1.7 (E_{total})^{0.8}$

Estimating uncertainty in 1-D river modelling

E_{tr} = Topography and roughness (formula depends on survey method)

Calibration uncertainty E_c is estimated from:

$E_c = (1/N)\{\Sigma(H_{model} - H_{obs})\} \times Max[\{Q_T/Q_c\}]$

N is the number of observation
H_{obs} is the observed water level
H_{model} is the modelled water level
Q_T is the design return period
Q_C is the calibration flow

Estimating uncertainty in 1-D river modelling

The discretion uncertainty Ed is estimated from:

$E_d = 0.1\ D\ \Delta X/L$

D is the bankfull depth
L is the backwater length
ΔX is the section spacing

Topography and roughness

Conventional field survey of floodplain topography

$E_{tr} = 0.12\ HD^{0.6}\ S^{0.11}\ (5Nr)^{0.65}$

$E_{max} = 1.7\ (E_{tr})^{0.8}$

Notation

HD	Hydraulic Mean Depth
S	River Slope
Nr	Roughness reliability number

Topography and roughness

Aerial survey providing spot levels on section lines

$E_{tr} = 0.12\ HD^{0.6}\ S^{0.11}\ (5Nr + Sn)^{0.65}$ (if Nr > 0)

$E_{tr} = 1.5\ S^{0.49}\ Sn^{0.83}$ (if Nr = 0)

$E_{max} = 1.7\ (E_{tr})^{0.8}$

S is the river slope

Sn Survey accuracy number

Topography and roughness

Floodplain topography determined from contour maps

$E_{tr} = 0.63\ HD^{0.35}\ S^{0.13}\ (Nr + Sn)$ (if Nr > 0)

$E_{tr} = 1.4\ S^{0.23}\ Sn^{1.18}$ (if Nr = 0)

$E_{max} = 2.1\ (E_{tr})^{0.8}$

Survey accuracy number Sn

Contour interval	Spot accuracy	Sn
250 mm	50 mm	0.08
500 mm	100 mm	0.17
1000 mm	250 mm	0.33
2000 mm	500 mm	0.66

Calibration reliability number Nr

Mean level drop (m)	Reliability number between gauges Nr
less than 1.0	0.0
1.0 +	0.1
4.0 +	0.4
10 +	0.7
15 +	0.8
20 +	0.9
no calibration data	1.0

Sources of uncertainty - Hydraulic modelling boundary conditions

Upstream boundary condition is usually the flow hydrograph

Downstream boundary is usually water level

Approximate backwater length L in km can be estimated from:

$L = 0.7D/s$

Where D is the depth of water in m and s is the slope of the river in m/km

Errors

- Errors are mistaken calculations or measurements
- Effects can be quantified once corrected
- "Random" human factors
- Can be managed (or eliminated?) by quality assurance and quality control procedures

Sources of errors - Hydro-meteorology

- Faulty rain gauges
- Change in data collection method, position, datum
- Uncalibrated current meters
- Malfunction of gauging sites
- Human error in transcribing data

Sources of errors - Hydraulic modelling

- Survey errors (closure, benchmarks)
- Gauge board datum
- Change in data collection method
- Human error in data entry into model
- Poor modelling procedure

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Exercise

Exercise Estimation of backwater length

Calculate the backwater length for each of the following rivers in Fiji in the list below

River	Location	Channel slope s (m/km)	Bankfull depth D (m)	Estimate of the backwater length (km) L = 0.7D/s
Nadrau Creek	WaiWai	0.857	4.8	
Waisali Creek	Toge	0.462	4.2	
Ba River	Karo	0.979	1.8	
Ba River	Navala	2.500	2.5	
Ba River	Nasolo	0.721	3.5	

Exercise on accuracy assessment

The following results were obtained from modelling a five year flood on a river in New Zealand.

Site number	Observed level (m above datum)	Model level (m above datum)	Difference (m)
1	22.95	22.97	0.02
2	21.80	21.72	-0.08
3	20.98	21.05	0.07
4	20.50	20.45	-0.05
5	19.49	19.58	0.09
6	17.44	17.49	0.05
7	16.17	16.17	0.00
8	13.90	13.92	0.02
9	13.05	13.04	-0.01
10	11.92	11.98	0.06

The flow was 205 m^3/s and the downstream level at the end of the reach was 11.70 m above datum. The length of the reach is 24.5 km and the bankfull depth of the channel is approximately 4.5 m. The hydraulic model contained 105 cross-sections and the flood plain data were obtained from contours plotted at 0.25 m vertical interval from an aerial survey.

What would be your assessment of the accuracy of the predicted 10 year and 100 year flood levels which correspond to 250 and 430 m^3/s respectively?

For these flows the hydraulic mean depth (area/breadth) under flood conditions is as follows.

River flood flow m^3/s	205	250	430
Hyrdraulic mean depth (m)	0.65	0.85	1.40

Can you estimate the improvement in accuracy of the predictions over the situation with no calibration data?

Morphological river flow processes

Learning objectives

- Understand the basics of river morphology
- Understand the key parameters that affect river morphology

Skills acquired

- Be able to comment on the possible effects of flood defence measures on river morphology
- To know the concept of "stream power"

Introduction

- Need to work with the river to reduce maintenance and capital costs
- Need to understand the processes and links between processes so we can work with the river

Introduction

- Many phenomena are difficult to understand and some remain unexplained
- Need to combine understanding from geological and physical sciences

Morphological principles

- Overview of river morphology
- Sediment transport
- Emphasis on introductory and mainly descriptive concepts
- Practical applications

River morphology

- Is concerned with shape, plan form, pattern and form of rivers
- Morphology depends on:
  - Water discharge
  - Sediment discharge
  - Sediment characteristics
  - Bed and bank composition
  - Other factors
  - and changes with time

Time scales of change

- Change can occur at a range of timescales:
  - short term - weeks/months to a few years
  - medium term - 10 to 100 of years
  - long term - 1000s or millions of years
- Engineers are interested in a human scale (short and medium term)

Stable channels

Different rivers and different reaches of river have different:

a) alignments

b) cross-section shapes

c) bed and bank material

d) slopes and valley characteristics

Stable channels

For equilibrium channels the channel

- width
- depth and
- slope

depend upon the discharge and sediment characteristics.

Relationships given by 'Regime theory'

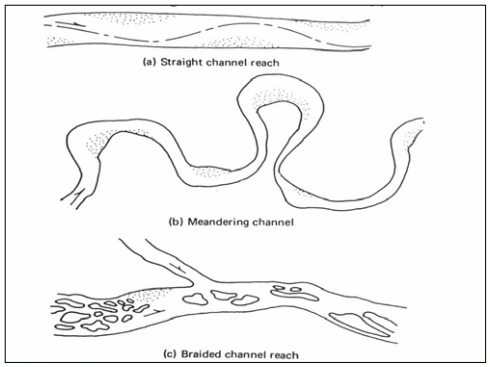
Stable channels

The channel forming discharge is called the dominant discharge which is frequently approximated by the bank-full discharge.

Channel plan form

- Straight channels
- Meandering channels - common, meanders move and may develop in time but system is dynamically stable
- Braided channels - system of channels which divide and rejoin and are dynamically stable

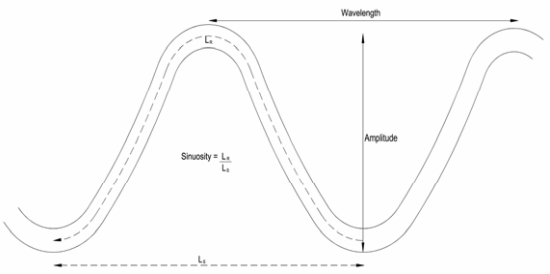
Channel plan form



Channel plan form

A meandering plan form is frequently characterised by the meander wave length, amplitude and sinuosity. These are related to the river discharge and sediment characteristics.

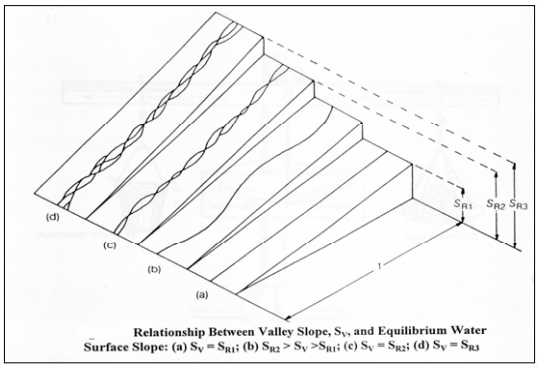
Channel plan form



Channel plan form

In braided river systems the intensity of the braiding, measured either by number of channels or length of river banks, tends to be constant at a specific location but varies with the dominant discharge, sediment characteristics and valley slope.

Channel plan form



Relationship Between Valley Slope, S_V, and Equilibrium Water Surface Slope: (a) $S_V = S_{R1}$; (b) $S_{R2} > S_V > S_{R1}$; (c) $S_V = S_{R2}$; (d) $S_V = S_{R3}$

Channel plan form: meanders

Knowledge allows:

a) assessment of stability of existing channel

b) design for river training scheme, river diversion, channel enhancement, river restoration

Channel plan form: meanders

Independent variables are:

a) water discharge

b) sediment discharge

c) sediment characteristics

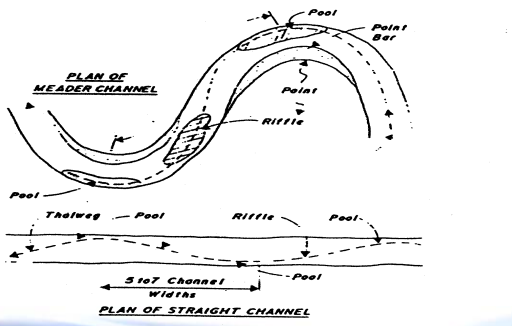
d) valley slope

Solution for plan form and cross-sectional shape can be obtained

Bed and bank features

- Typical features associated with meandering rivers
- Cross-section shape on bend (deeper on outside of bend)
- Pool and riffle sequences - linked to plan form
- Occurrence of point bars - deposits of sediment on inside of channel bends
- Undercutting of banks on outside of bends

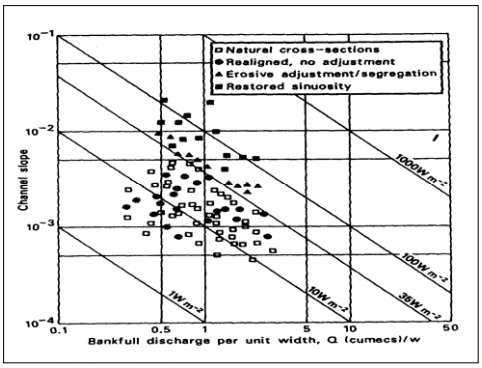
Elements of channel form



Stream power

- Stream power is the power (or rate of work) required by the river to transport water and sediment
- Important independent variable which affects channel stability and river morphology
- Stream power is a function of gradient and discharge

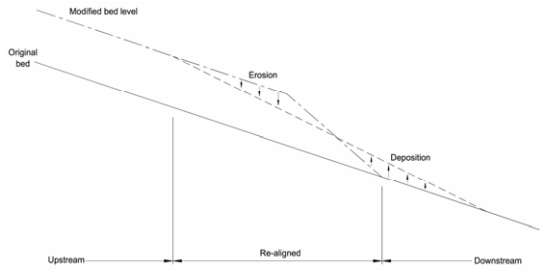
Stream power



Physical impacts - straightening

- Straightening a meandering stream increases slope locally
- Increased slope causes increased sediment transport
- Increased sediment transport causes upstream degradation
- Increased sediment transport causes downstream deposition where slope flattens in the natural reach

Straightened channel



Upstream erosion and downstream deposition in a straightened channel

Gasegase (Vaimoso) Stream, Sinamoga

Physical impacts - enlarged channels

- Reduces unit stream power and causes sediment deposition
- Over-widened channels reduce flow velocity
- Sediment deposition likely to result in channel returning to original equilibrium
- Sediment deposition occurs forming permanent morphological features
- Maintenance regime required to maintain enlarged channel

Physical impacts - embankments

- Larger flows are confined
- Greater velocities associated with larger flows may affect channel morphology

Physical impacts - clearance of vegetation

- Trees and bushes stabilise banks - their removal can result in bank erosion
- Emergent vegetation stabilises banks and creates berms and ledges - removal can result in erosion and channel widening

Sediment transport

Assessing sediment load is a vital part of understanding river behaviour

- Bed load - moves on or near the bed
- Suspended load - carried in suspension
- Total load sum of bed and suspended loads
- Wash load - finest portion of load (silt and clay permanently in suspension). Wash load is supply limited and is washed through the system

Sediment load is key determinant of the stable river

Prediction of sediment load

Many formulae of three main types:

- Bed load formulae
- Suspended load formulae
- Total load formulae

Recommended use Ackers-White total load formula

Improved practices (1)

- Understand morphological diversity
- Undertake geomorphological assessment
- Retain morphological diversity
- Minimal reduction in channel properties
- Minimum disruption to bed and banks during and after construction

Improved practices (2)

- Preserve pool and riffle sequences where possible
- Examine susceptibility of upstream channel to morphological change
- Avoid creating very deep pools
- Avoid over widening
- Avoid artificial liners
- Set back embankments

Mitigation, enhancement, restoration techniques

- In-stream devices e.g deflectors, low weirs
- Reinstate substrate
- Reinstate meanders - if appropriate
- Create non-uniform channels
- Promote bank stability with tree and bush planting
- Plan careful management and maintenance

Exercise

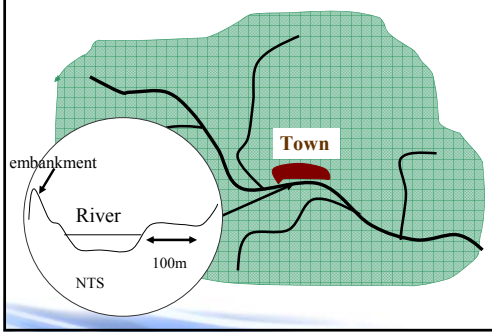
Impact of river works on the morphology and sediments of the river channel

General information

At the position shown in the catchment, Figure 1, a reach of the river was straightened and widened for flood defence purposes. A flood embankment was placed adjacent to the river on the left bank to protect property and on the right bank set back 100m on the flood plain to protect arable farm land.

This work was undertaken twenty years previously. Dredging has been undertaken twice within the twenty years. The substrate of the river is gravel. Tree and bush maintenance has been undertaken on the left bank and grass cutting on the right bank.

Figure 1



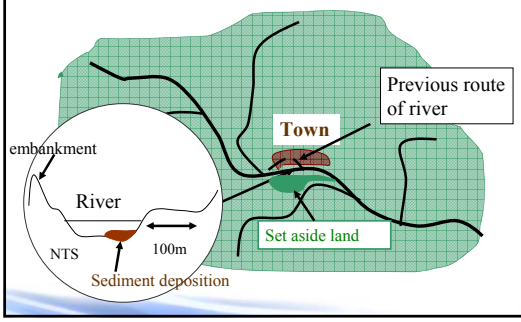
Task 1

Describe the morphological problems which may be occurring in the river due to the flood defence works

More specific information

- The sediment deposition is becoming a problem in reducing the channel flood capacity but ongoing dredging maintenance is too costly
- The ecological diversity of the channel is poor at low flows and there is little diversity on the right floodplain
- The previous alignment of the channel is shown in Figure 2
- The land protected by the flood embankment on the right bank has been designated set aside land

Figure 2



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Task 2

Describe and discuss the possibilities for this channel to try and

a) **maintain flood capacity**

b) **providing more sustainable morphological conditions**

c) **improve ecological diversity**

Methods of flood defence

Learning objectives

- Understand the different structural measures and non-structural measures available
- Understand the effects of these changes

Skills acquired

- To be able to make an informed assessment of the different flood mitigation measures available for a particular site

Methods of flood defence

Flood alleviation (structural measures)

- Hazard is reduced but not eliminated
- High capital and maintenance cost

Development control (non-structural)

- Land use planning in flood risk areas
- May be difficult politically

Flood warning (non-structural)

- Loss of life reduced
- Small reduction in other losses

Structural measures

Aims

- Reduce flood levels
- Reduce flood flows
- Reduce flood impact

Solutions

- Flood banks and walls
- Channel works
- Flood storage (on/off line)
- Flood relief channels
- Tidal flood barrier
- Pumping
- Redevelopment

Choice of flood defence option

Constraints

- Topography and land availability
- Cost
- Planning considerations
- Design standards
- Public views
- Environmental issues

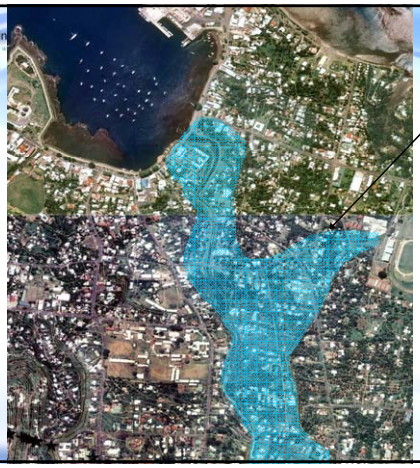
Possibilities

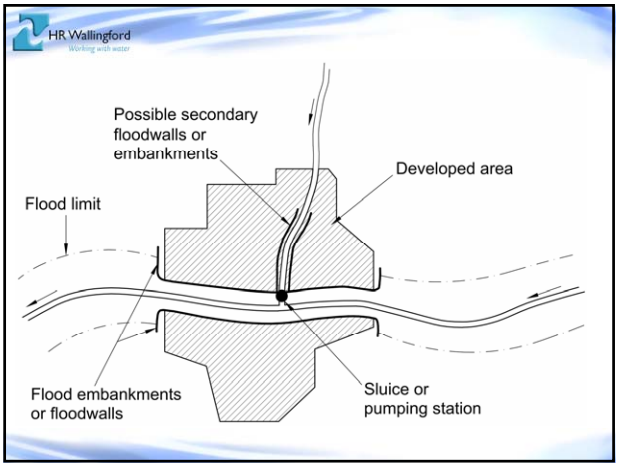
- Combination of options (e.g. walls and warning)
- Temporary defences

Non-structural measures

i.e. do not change the river hydraulics

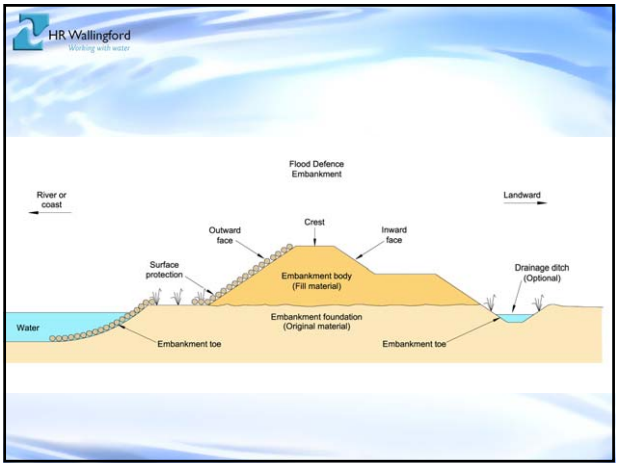
- **Flood forecasting and warning**
- **Planning and building control**
- **Building restrictions**
- **Retrofit runoff control**
- **Flood proofing**
- **Flood insurance …. last resort**





Flood banks

- Simple and effective
- Pumping or storage required for runoff from defended area
- Limited design standard (e.g. 100 years), then overtop or fail
- Often visually intrusive
- May cause raised upstream levels (backwater effect)
- May cause raised downstream levels (loss of storage)



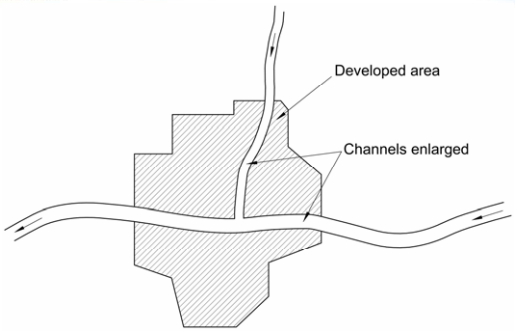
Flood banks

Design considerations:

- Location and dimensions
- Geology/soils/hydrogeology
- Bank stability
- Seepage
- Bank protection and access
- Future modifications to design

Floodwalls

- Take limited space
- Design for hydrostatic loading + freeboard
- Reinforced concrete or sheet piles
- Impervious curtain to prevent seepage underneath
- Face with brick or stone/aggregate finish
- Minimum height for public safety
- In association with temporary defences



Channel "improvements"

Increase conveyance capacity:

- Increase cross-sectional area
- Reduce roughness
- Remove bends
- Increase water surface slope
- 2/3-stage channels

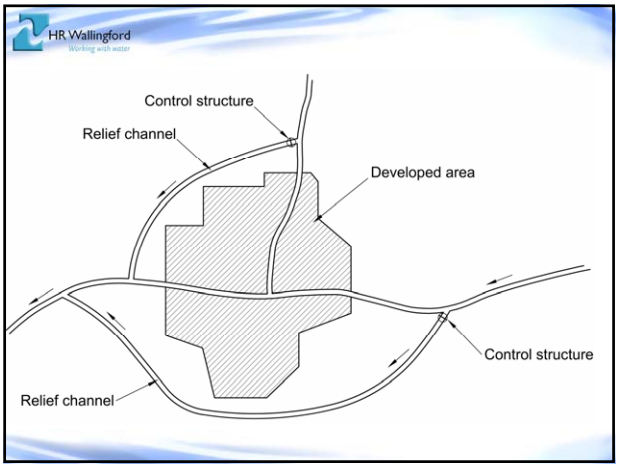
Channel "improvements"

Issues/problems:

- Decreased depths
- Increased flow velocities
- Potential siltation at low flows
- Dredging may be ongoing
- Potential morphological re-adjustment
- Environmental impact and disturbance

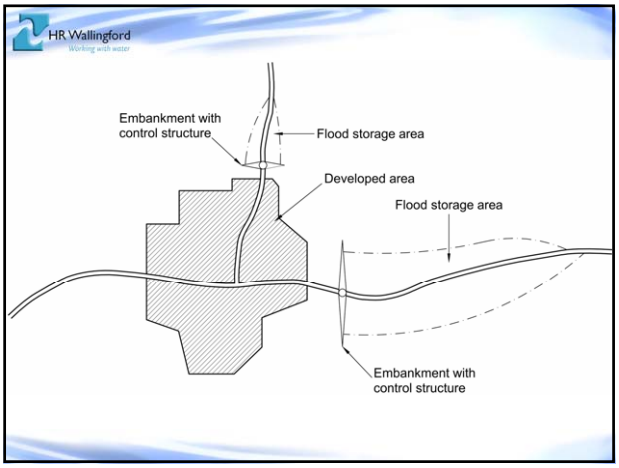
Reducing roughness

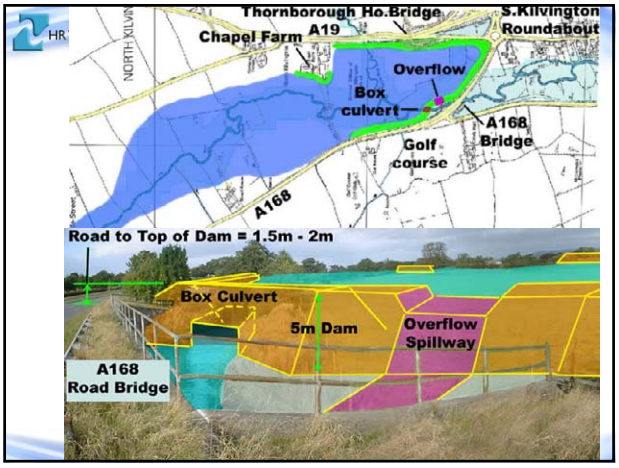
- Clear banks of dead or overhanging trees
- Seasonal reed and weed removal
- Use of lined channels in urban areas (e.g. concrete)
- May not be environmentally acceptable



Flood relief or bypass channel

- Water returned to river below flood risk area
- Requires clear route and suitable topography
- Control structure at upstream end, e.g. weir or sluice



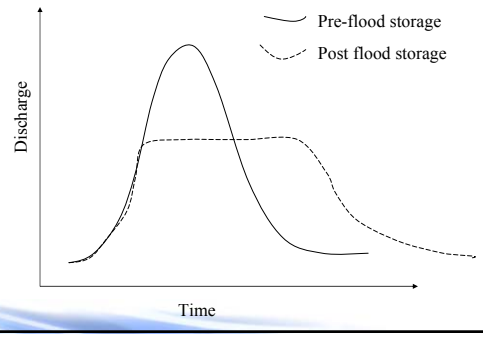


Storage reservoirs

- In many parts of the world it is common practice to attenuate runoff from new developments
- Storage reservoirs store excess flood water and limit flow passing downstream
- Control structures required
- Can cause increased flood risk downstream if incorrectly designed
- Issues of ownership, operation and maintenance

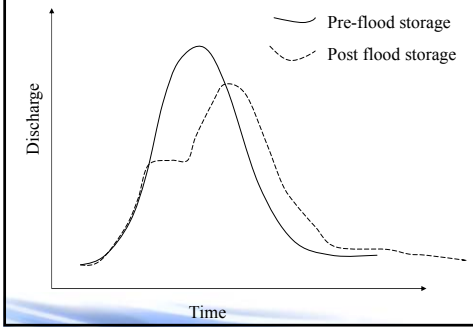
Impact on hydrograph

Storage adequate



Impact on hydrograph

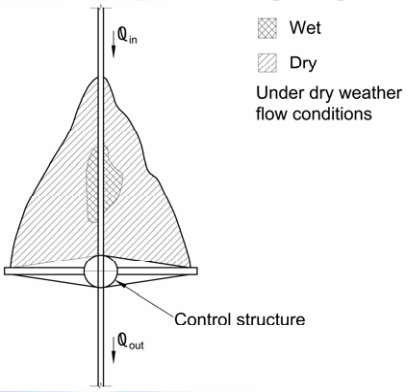
Filled storage



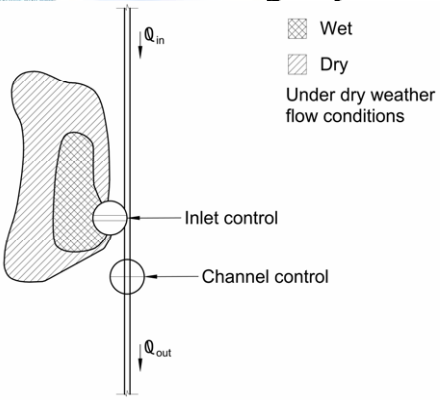
Storage reservoirs

- **On-line reservoir controls:** Orifice; Flume; Pipe; Weir; Notch; Vertical gate; Radial gate; Tilting gate or weir
- Spillway for overflow - energy dissipation needed
- **Off-line reservoir**
- Usually has control on main channel
- Control on bank into storage area
- Provision to drain reservoir after storm

Flood storage layouts: on-line



Flood storage layouts: off-line



Storage reservoirs

Other considerations:

- Large land requirement
- Often not viable for large rivers
- Environmentally acceptable
- Local amenity and recreation
- Nature conservation
- Land use of areas to be flooded (e.g. agriculture)
- Safety (reservoir legislation)

Pumping

- Effective method of flood control for relatively small areas and volumes
- Widespread use in
  - areas with poor drainage
  - for local runoff impounded by flood banks
  - areas affected by mining subsidence
- Static head typically 3 to 6 metres
- Pumps may be diesel or electric
- Channel must have adequate flow and storage capacity

Flood forecasting and warning

- **Fluvial and tidal systems have three components:**
  - Detection
  - Forecasting
  - Warning dissemination
- **Achieving response is crucial**
- **Understand the needs of different parties (public, council, police)**

Flood warning

- **Messages coded for recipients - civil protection services and general public**
- **Effectiveness depends on several factors:**
- **Having awareness of a warning**
- **Being available to respond**
- **Being able to respond**
- **Knowing how to respond**

Post-flood recovery

- **Relief for those affected**
- **Reconstruction of damaged infrastructure**
- **Regeneration of the environment and productivity in the affected area**
- **Review of flood management to improve processes and policies**

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Exercise

Flood defence

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General Information

At the position shown in the catchment, Figure 1, a reach of the river was straightened and widened for flood defence purposes. A flood embankment was placed adjacent to the river on the left bank to protect property and on the right bank set back 100 m on the flood plain to protect farm land

This work was undertaken twenty years previously. Dredging has been undertaken twice within the 20 years. The substrate of the river is gravel. Tree and bush maintenance has been undertaken on the left bank and grass cutting on the right bank.

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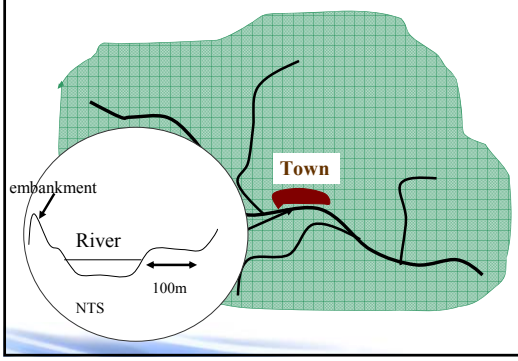
Figure 1



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Task 1

In view of the fact that the town was being developed the river was straightened, widened and embankments raised.

What was the likely impact of:

a) the development

b) the flood defences

on the flooding locally, upstream and downstream

What are the likely environmental impacts of the flood management solution?

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Task 2

Figure 2 shows the hydrograph before development, widening and straightening.

Sketch the impact of the development and the flood defence works on the hydrograph

Figure 3 shows the stage versus discharge relationship at the site before development, widening and straightening.

Sketch the impact of the development and the flood defence works on this relationship

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Figure 2

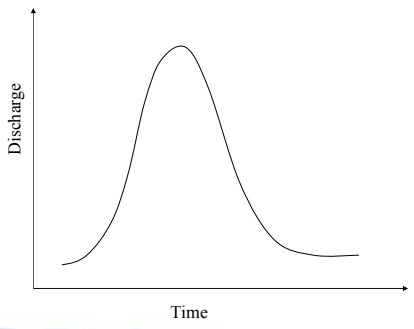

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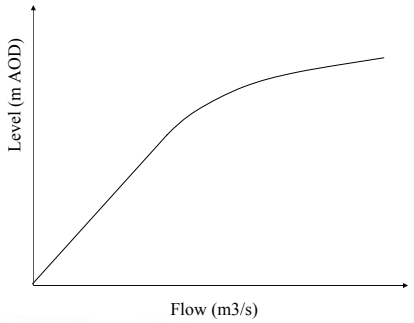
Figure 3



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Task 3

There were possibly other options for managing the increased run-off from the new development. Describe these options and discuss the limitations and likely positive and negative impacts that they may have had.

Include a sketch of the impacts on the post-development hydrograph (Figure 4) of the different options.

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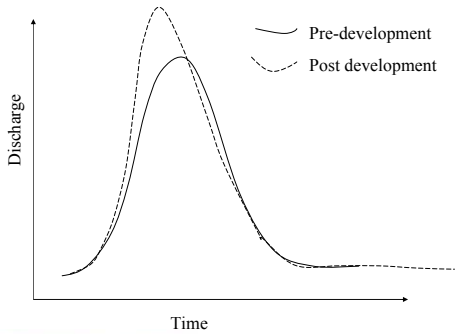
Figure 4



An introduction to HEC-RAS

Learning objectives

- Understand the components of HEC-RAS software
- Understand the different parts of the HEC-RAS software interface
- Understand how to develop a HEC-RAS project

Skills acquired and reasons for using HEC-RAS

- To know the functionality of the HEC-RAS software
- To appreciate how to develop a simple river model using HEC-RAS

Background to HEC-RAS

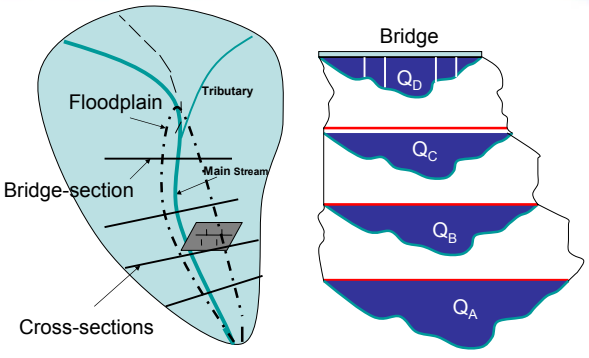
HEC-RAS = Hydrologic Engineering Center's River Analysis System

Developed by the US Army Corps of Engineers over a number of years

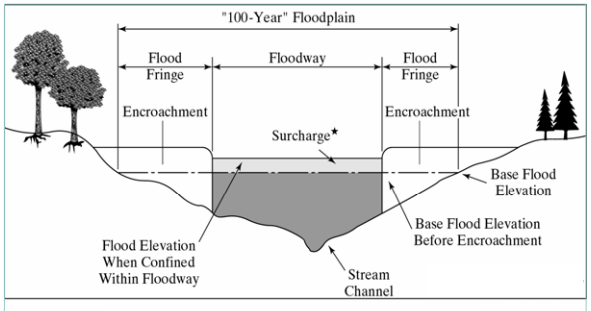
Latest version is 3.1.3 May 2005

Available for free from the internet (www.hec.usace.army.mil) together with comprehensive manuals and references in PDF format

1 in 100 year floodplain



The floodplain



What does HEC-RAS do?

HEC-RAS is an integrated package of hydraulic analysis programs, in which the user interacts with the system through the use of a Graphical User Interface

The program can perform steady and unsteady flow water surface calculations

In future it will include a sediment transport module

Uses of HEC-RAS

To estimate flood levels

To assess the design of flood mitigation measures e.g. flood storage, bypass channels, flood walls

To assess the design of bridges and culverts

Effects of urbanisation on water levels

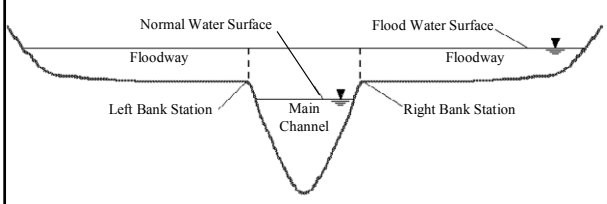
Floodplain regulation

Dam breaches

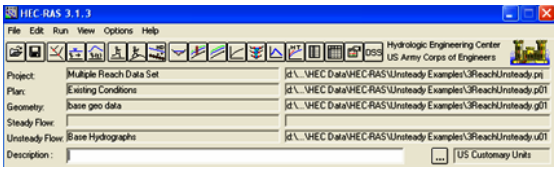
HEC-RAS – Input and output

Input = cross-section geometry and flow rates

Output = flood water elevations



HEC-RAS main window



Steps in developing a hydraulic model with HEC-RAS

- Start a new project
- Enter the geometric data
- Enter roughness data for cross-sections
- Enter flow data and boundary conditions
- Performing the hydraulic calculations
- Viewing and printing the results

Steps in developing a hydraulic model with HEC-RAS

- First draw the river schematic
- After the river schematic has been draw enter the cross-section data
- Each cross-section has a:
  - River name
  - Reach name
  - River station
  - Description

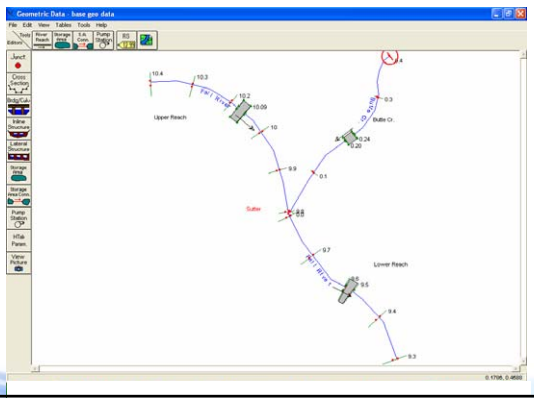
What data is required to build a HEC-RAS model

- Cross-section data in the form of x and y coordinates
- Topographic details of the floodplain
- Boundary conditions – what are these?

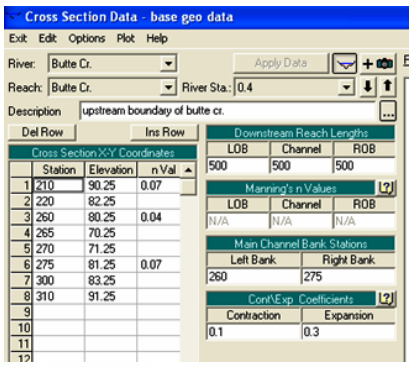
Hydraulic model boundary conditions

- All hydraulic models requiring boundary conditions
- Upstream boundary is normally formed by a flow input e.g. a steady flow or a flow hydrograph
- The downstream boundary can be formed by a water depth or stage vs discharge rating curve

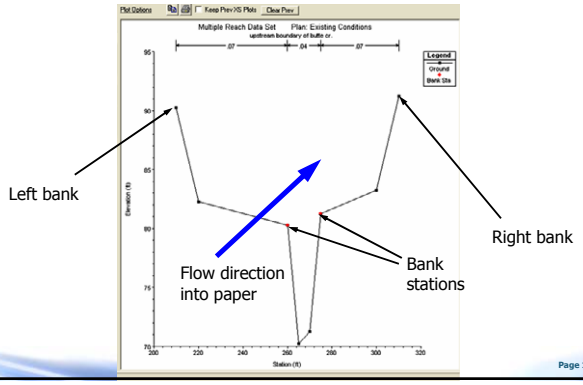
Geometric data window



Basic data required for cross-sections



Cross-section conventions



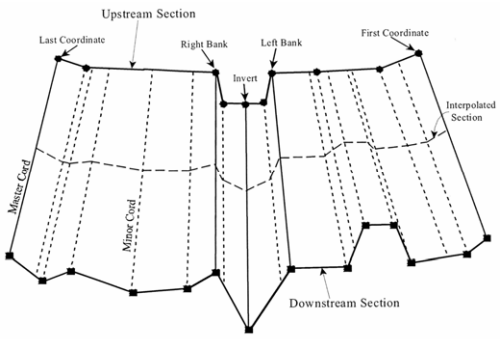
Format cross-section data

Station (x axis)	Elevation (y axis)
0	20
10	21
15	19
20	15
30	15
40	22
.	.
.	.
.	.
.	.

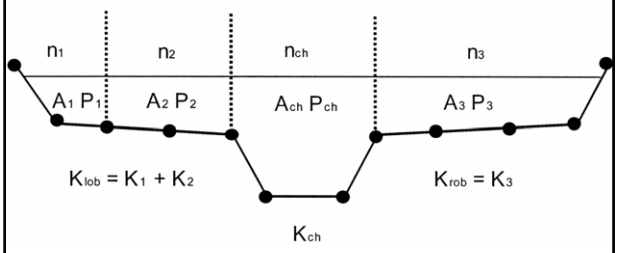
Left bank

Need to add the distance known as the "Reach length" between each cross-section

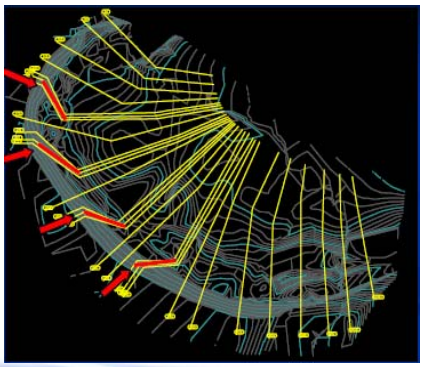
Cross-section interpolation



Cross-section sub-division for conveyance calculation



Orientation of cross-sections



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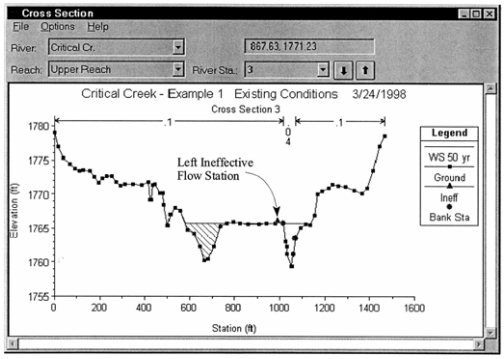
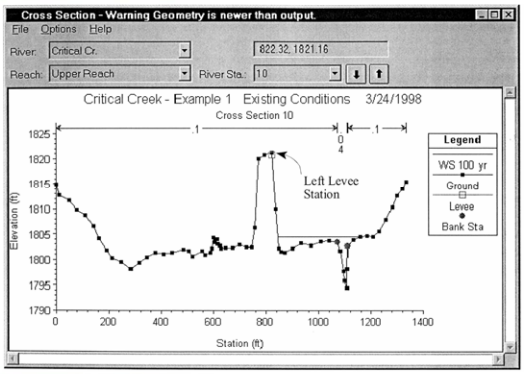
Working with water

Ineffective flow areas



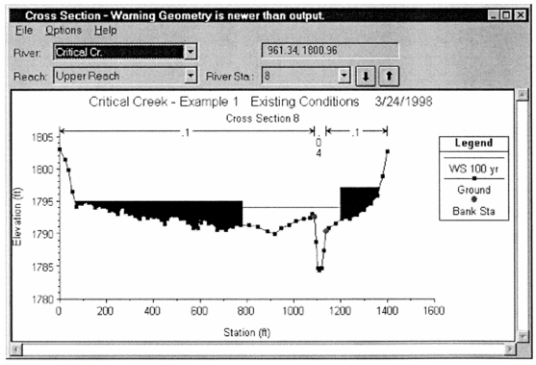
Page 22

Levees



Page 23

Obstructions



Page 24

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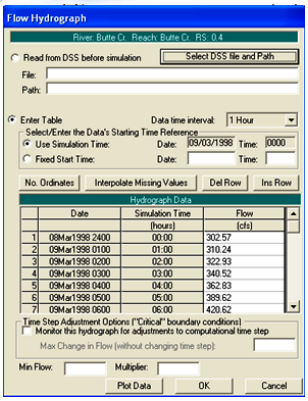
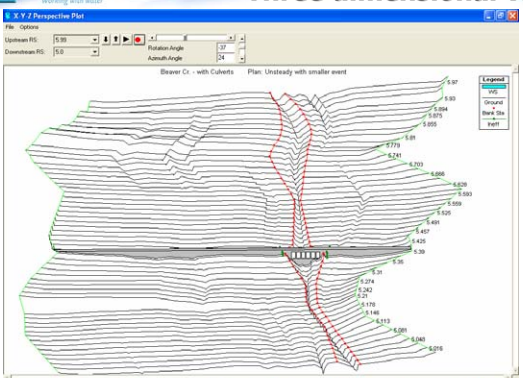
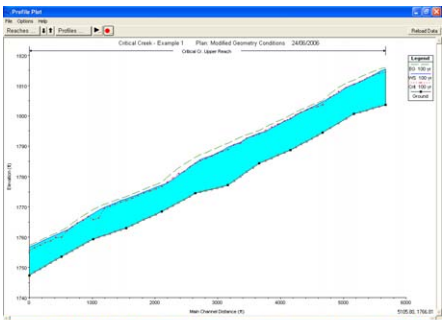
Flow hydrograph data



Three dimensional view



Longitudinal profile



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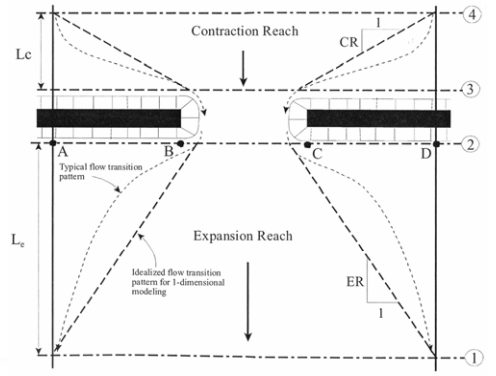
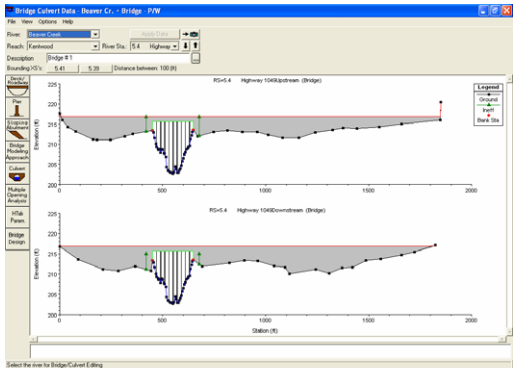
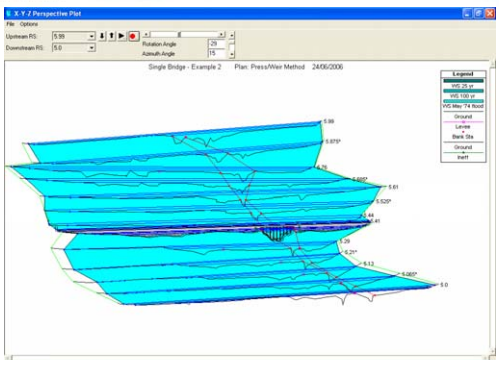
Modelling bridges



Modelling of structures - bridges



Modelling of structures - bridges



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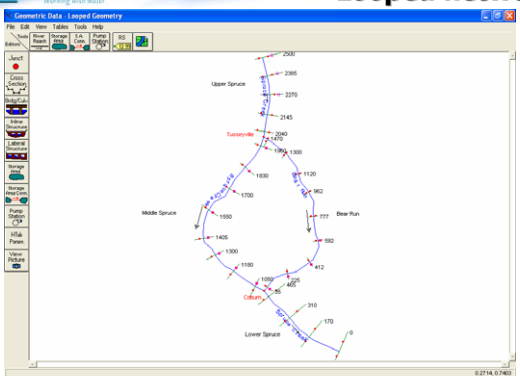
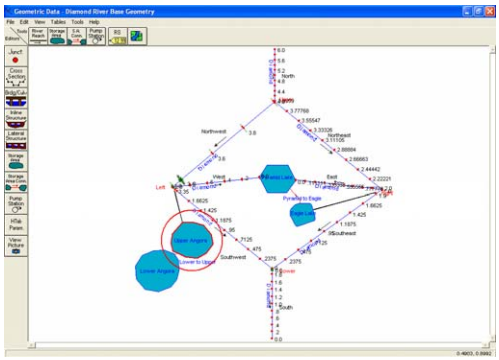
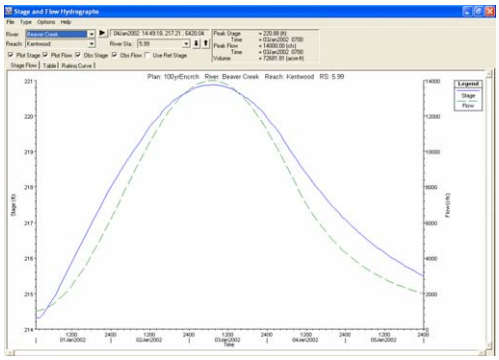
Looped networks



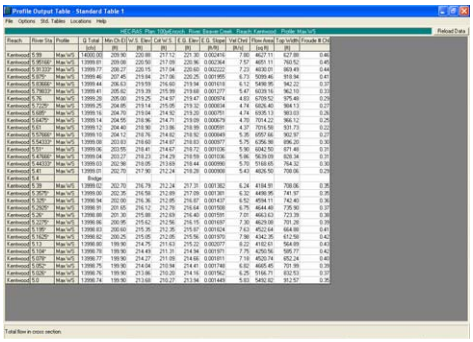
Storage areas



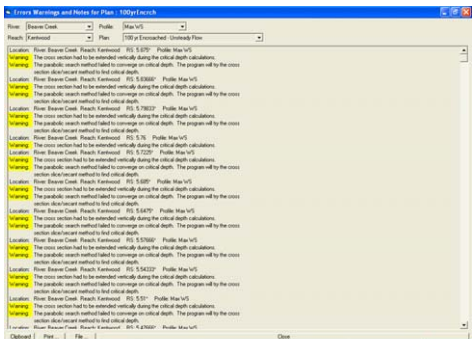
Results – flow and stage hydrographs



Results – tables



Errors and warnings



APPENDIX F

Exercises

Appendix F Exercises

Exercise 1 Using HEC HMS to estimate flood flows for the Vaisigano

The purpose of this exercise is to estimate flood flows for different design and historical storms using a HEC-HMS hydrological model of the Vaisigano River catchment. The Vaisigano has been modelled in HEC-HMS by splitting it up into 12 different **Subbasins** as shown in Figure 1.

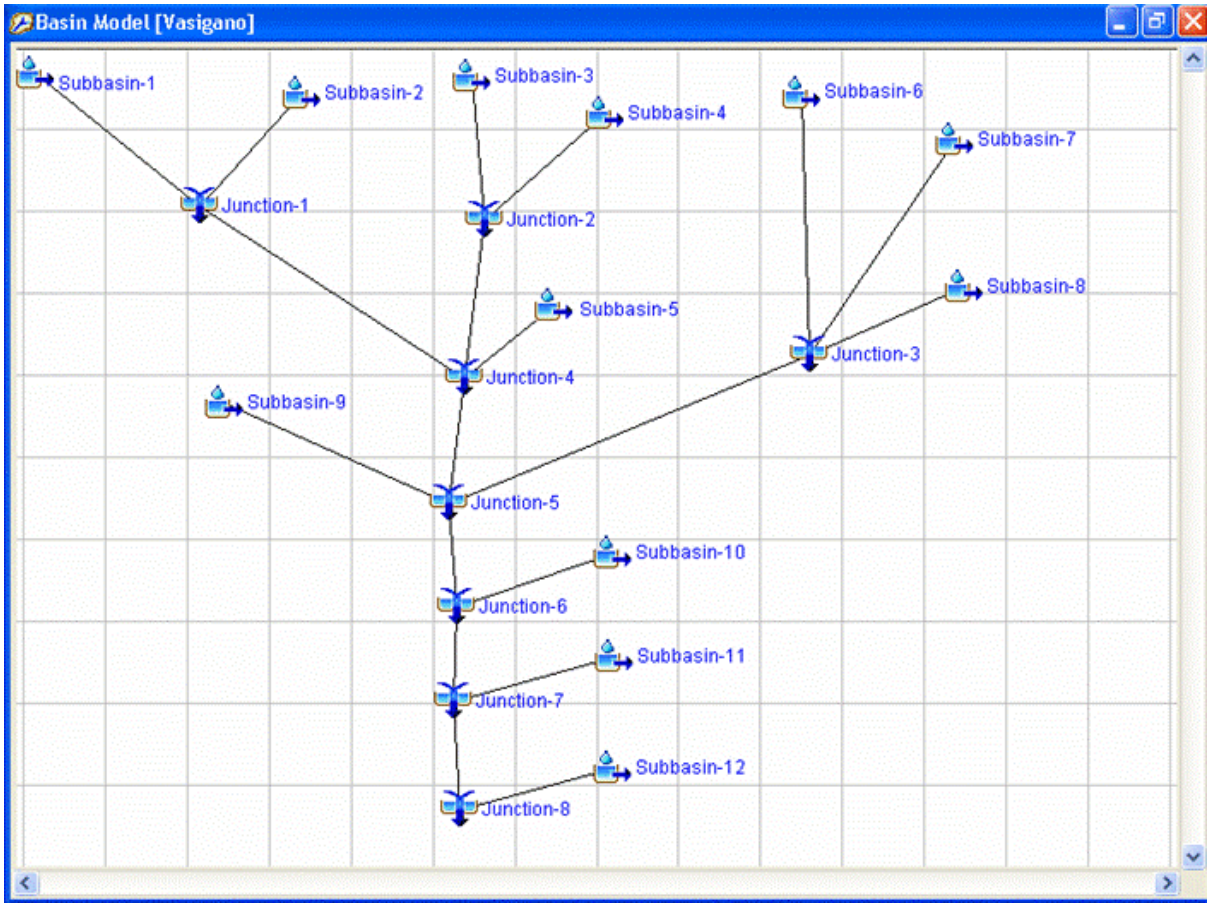


Figure 1 HEC-HMS model of the Vaisigano River catchment

Each of the Vaisigano River catchment Subbasins has been modelled using a kinematic wave method. ***Before you start the exercise read pages 64 to 67 of the HEC-HMS technical manual to give you the background to this hydrological modelling method.***

Now start the exercise. The basic model has already been set up. However, you will have to enter the various parameters for each of the Subbasins. These are detailed in the Tables 1 and 2 below.

Table 1 Subbasin details

Subbasin number	Collector	Subcollector	Plane 1	Plane 2	Options	Loss 1
1	Subreaches = 5 Shape = Trapezoid	Subreaches = 5 Shape = Trapezoid	Length = 3634 Slope = 0.07 Roughness = 0.15 Area = 100% Routing steps = 5	Leave this empty	Leave this empty	Initial loss = 10 mm Constant rate = 2 mm/hr Impervious % = 0
2	Subreaches = 5 Shape = Trapezoid	Subreaches = 5 Shape = Trapezoid	Length = 4711 Slope = 0.045 Roughness = 0.15 Area = 100% Routing steps = 5	Leave this empty	Leave this empty	Initial loss = 10 mm Constant rate = 2 mm/hr Impervious % = 0
3	Subreaches = 5 Shape = Trapezoid	Subreaches = 5 Shape = Trapezoid	Length = 3651 Slope = 0.051 Roughness = 0.15 Area = 100% Routing steps = 5	Leave this empty	Leave this empty	Initial loss = 10 mm Constant rate = 2 mm/hr Impervious % = 0
4	Subreaches = 5 Shape = Trapezoid	Subreaches = 5 Shape = Trapezoid	Length = 3269 Slope = 0.053 Roughness = 0.15 Area = 100% Routing steps = 5	Leave this empty	Leave this empty	Initial loss = 10 mm Constant rate = 2 mm/hr Impervious % = 0
5	Subreaches = 5 Shape = Trapezoid	Subreaches = 5 Shape = Trapezoid	Length = 1578 Slope = 0.04 Roughness = 0.15 Area = 100% Routing steps = 5	Leave this empty	Leave this empty	Initial loss = 10 mm Constant rate = 2 mm/hr Impervious % = 0
6	Subreaches = 5 Shape = Trapezoid	Subreaches = 5 Shape = Trapezoid	Length = 2811 Slope = 0.069 Roughness = 0.055 Area = 100% Routing steps = 5	Leave this empty	Leave this empty	Initial loss = 10 mm Constant rate = 2 mm/hr Impervious % = 10
7	Subreaches = 5 Shape = Trapezoid	Subreaches = 5 Shape = Trapezoid	Length = 878 Slope = 0.044 Roughness = 0.055 Area = 100% Routing steps = 5	Leave this empty	Leave this empty	Initial loss = 10 mm Constant rate = 2 mm/hr Impervious % = 10
8	Subreaches = 5 Shape = Trapezoid	Subreaches = 5 Shape = Trapezoid	Length = 4590 Slope = 0.039 Roughness = 0.15 Area = 100% Routing steps = 5	Leave this empty	Leave this empty	Initial loss = 10 mm Constant rate = 2 mm/hr Impervious % = 2
9	Subreaches = 5 Shape = Trapezoid	Subreaches = 5 Shape = Trapezoid	Length = 3650 Slope = 0.028 Roughness = 0.15 Area = 100% Routing steps = 5	Leave this empty	Leave this empty	Initial loss = 10 mm Constant rate = 2 mm/hr Impervious % = 5
10	Subreaches = 5 Shape = Trapezoid	Subreaches = 5 Shape = Trapezoid	Length = 2770 Slope = 0.02 Roughness = 0.15 Area = 100% Routing steps = 5	Leave this empty	Leave this empty	Initial loss = 10 mm Constant rate = 2 mm/hr Impervious % = 0
11	Subreaches = 5 Shape = Trapezoid	Subreaches = 5 Shape = Trapezoid	Length = 1600 Slope = 0.086 Roughness = 0.010 Area = 100% Routing steps = 5	Leave this empty	Leave this empty	Initial loss = 10 mm Constant rate = 2 mm/hr Impervious % = 15
12	Subreaches = 5 Shape = Trapezoid	Subreaches = 5 Shape = Trapezoid	Length = 961 Slope = 0.0007 Roughness = 0.10 Area = 100% Routing steps = 5	Leave this empty	Leave this empty	Initial loss = 10 mm Constant rate = 2 mm/hr Impervious % = 20

Table 2 Subbasin details continued

Subbasin number	Loss 2	Subbasin	Channel
1	Leave this empty	Downstream = Junction-1 Area = 4.978 km^2 Loss method = Initial and constant Transform method = Kinematic wave Baseflow method = none	Route upstream = No Routing method = Kinematic wave Length = 3634 Slope = 0.07 Subreaches = 5 Shape = Trapezoid Manning's n = 0.05 Bottom width (m) = 20 Side slope = 5
2	Leave this empty	Downstream = Junction-1 Area = 4.231 km^2 Loss method = Initial and constant Transform method = Kinematic wave Baseflow method = none	Route upstream = Yes Routing method = Kinematic wave Length = 4711 Slope = 0.045 Subreaches = 5 Shape = Trapezoid Manning's n = 0.05 Bottom width (m) = 20 Side slope = 5
3	Leave this empty	Downstream = Junction-2 Area = 5.607 km^2 Loss method = Initial and constant Transform method = Kinematic wave Baseflow method = none	Route upstream = No Routing method = Kinematic wave Length = 3651 Slope = 0.051 Subreaches = 5 Shape = Trapezoid Manning's n = 0.05 Bottom width (m) = 30 Side slope = 5
4	Leave this empty	Downstream = Junction-2 Area = 1.772 km^2 Loss method = Initial and constant Transform method = Kinematic wave Baseflow method = none	Route upstream = Yes Routing method = Kinematic wave Length = 3269 Slope = 0.053 Subreaches = 5 Shape = Trapezoid Manning's n = 0.05 Bottom width (m) = 25 Side slope = 5
5	Leave this empty	Downstream = Junction-4 Area = 0.724 km^2 Loss method = Initial and constant Transform method = Kinematic wave Baseflow method = none	Route upstream = Yes Routing method = Kinematic wave Length = 1578 Slope = 0.04 Subreaches = 5 Shape = Trapezoid Manning's n = 0.05 Bottom width (m) = 30 Side slope = 5
6	Leave this empty	Downstream = Junction-3 Area = 2.009 km^2 Loss method = Initial and constant Transform method = Kinematic wave Baseflow method = none	Route upstream = Yes Routing method = Kinematic wave Length = 2881 Slope = 0.069 Subreaches = 5 Shape = Trapezoid Manning's n = 0.05 Bottom width (m) = 30 Side slope = 5
7	Leave	Downstream = Junction-3	Route upstream = Yes

	this empty	Area = 6.346 km^2 Loss method = Initial and constant Transform method = Kinematic wave Baseflow method = none	Routing method = Kinematic wave Length = 4353 Slope = 0.044 Subreaches = 5 Shape = Trapezoid Manning's n = 0.05 Bottom width (m) = 30 Side slope = 5
8	Leave this empty	Downstream = Junction-3 Area = 3.020 km^2 Loss method = Initial and constant Transform method = Kinematic wave Baseflow method = Recession	Route upstream = Yes Routing method = Kinematic wave Length = 4590 Slope = 0.039 Subreaches = 5 Shape = Trapezoid Manning's n = 0.05 Bottom width (m) = 25 Side slope = 5
9	Leave this empty	Downstream = Junction-5 Area = 2.55 km^2 Loss method = Initial and constant Transform method = Kinematic wave Baseflow method = Recession	Route upstream = Yes Routing method = Kinematic wave Length = 3650 Slope = 0.028 Subreaches = 5 Shape = Trapezoid Manning's n = 0.05 Bottom width (m) = 50 Side slope = 5
10	Leave this empty	Downstream = Junction-6 Area = 1.736 km^2 Loss method = Initial and constant Transform method = Kinematic wave Baseflow method = Recession	Route upstream = No Routing method = Kinematic wave Length = 2770 Slope = 0.020 Subreaches = 5 Shape = Trapezoid Manning's n = 0.05 Bottom width (m) = 60 Side slope = 5
11	Leave this empty	Downstream = Junction-7 Area = 0.84 km^2 Loss method = Initial and constant Transform method = Kinematic wave Baseflow method = Recession	Route upstream = Yes Routing method = Kinematic wave Length = 1600 Slope = 0.0086 Subreaches = 5 Shape = Trapezoid Manning's n = 0.05 Bottom width (m) = 70 Side slope = 5
12	Leave this empty	Downstream = Junction-8 Area = 0.435km^2 Loss method = Initial and constant Transform method = Kinematic wave Baseflow method = Recession	Route upstream = Yes Routing method = Kinematic wave Length = 961 Slope = 0.0007 Subreaches = 5 Shape = Trapezoid Manning's n = 0.05 Bottom width (m) = 80 Side slope = 5

There are six different Meteorologic models that have been set up in the HEC-HMS model together with their relevant control specifications. These Meteorologic models are as follows:

- 1 in 100 year 1 hour duration storm with the file name 1h_100y_ARI;
- 1 in 100 year 2 hour duration storm with the file name 2h_100y_ARI;
- 1 in 100 year 3 hour duration storm with the file name 3hr_100y_ARI;
- 1 in 100 year 4.5 hour duration storm with the file name 4.5hr_100y_ARI;
- 2001 flood with rainfall data from Dr Yeo's study on the 2001 flood with the filename 2001 flood;
- 2001 flood with rainfall data from the Meteorology Division's on the 2001 flood with the filename 2001 flood Meteo.

The first step is to run the HEC-HMS model with all for all of these different rainfall events. Refer to the HEC-HMS manual if you are having difficulties. For each run view the hydrograph that is produced at Junction-8 of the model.

Which of the 1 in 100 year storms generates the highest peak flow?

Export the data for each of the hydrographs to a spreadsheet.

Now use these six hydrographs to run the HEC-RAS model you built in Exercise 5. Refer to the HEC-RAS user manual if you are having difficulties importing this data.

Which of the 1 in 100 year flood hydrographs gives you the highest water levels?

HEC-RAS exercises

Exercise 1 Setting up a steady flow river model

Using Windows Explorer set up a sub-directory on your computer called C:\HEC_RAS_Examples. Open the HEC-RAS program by double clicking on the HEC-RAS icon. The main window should appear as shown in Figure 1.

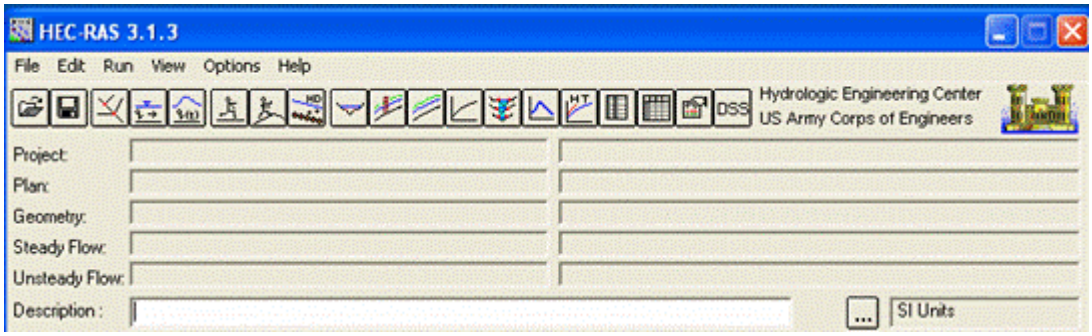


Figure 1 HEC-RAS main window

The first set in opening a HEC-RAS application is to start a new project. Go to the **File** menu on the main window and select **New Project**. The New Project window should appear as shown in Figure 2.

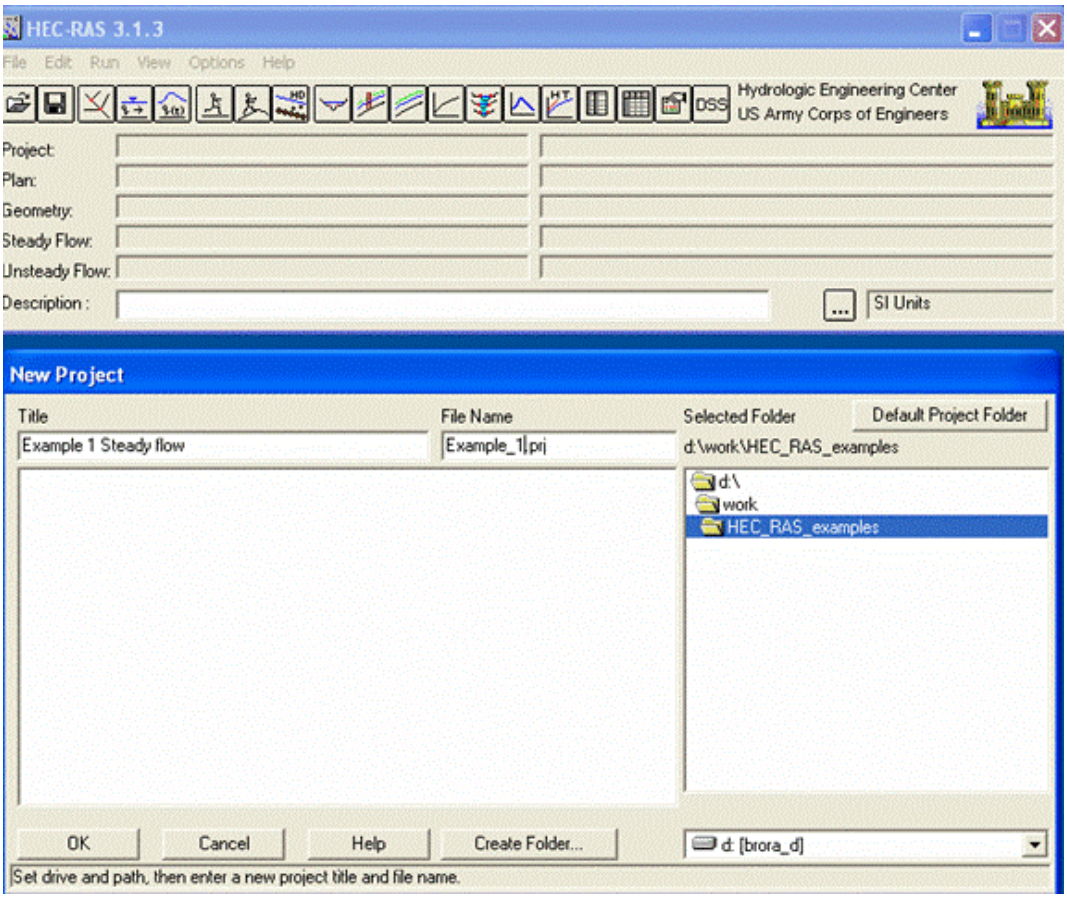


Figure 2 New project window

Set the drive to the C:\HEC_RAS_Examples directory. In the **Title** box enter "Example 1 Steady Flow" and in the File Name box enter "Example_1.prj". Note it is important that you check under the **Options** menu that the **Unit System** is set to **SI** (i.e. Standard International or metric units).

The next step in developing a hydraulic river model using HEC-RAS is to enter the geometric data. This is done by selecting the **Geometric Data** from the **Edit** menu on the HEC-RAS main menu. Once this option is selected the geometric data window will appear as shown in Figure 3.

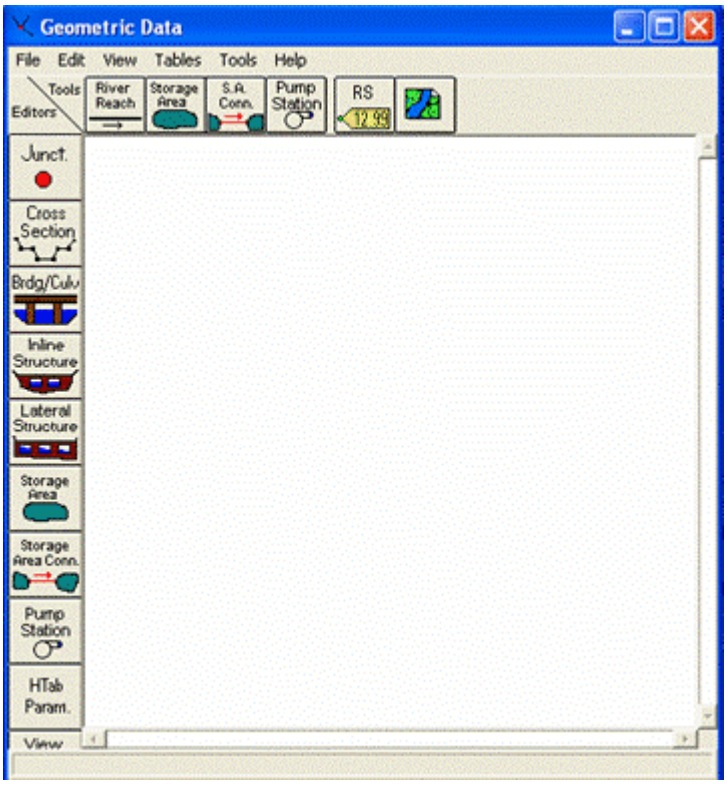


Figure 3 Geometric data window

In this example a simple hydraulic model of a river is going to be developed as shown in Figure 4. Draw the river system schematic by performing the following steps:

1. Click the **River Reach** button on the geometric data window.

2. Move the mouse pointer over to the drawing area and place the pointer at the location where you would like to start drawing the river reach.

3. Press the left mouse button once to start drawing the reach. Move the mouse pointer and continue to press the left mouse buttons to add additional points to the line segment. To end the drawing of the reach, double click the mouse button and the last button of the reach will be placed at the current mouse pointer location. All reaches must be drawn from an upstream to a downstream direction.

4. Once the reach is drawn the interface will prompt you to enter an identifier for the **River** name and the **Reach** name. In this example the River name should be entered as **Main River** and the Reach name as **Upper**.

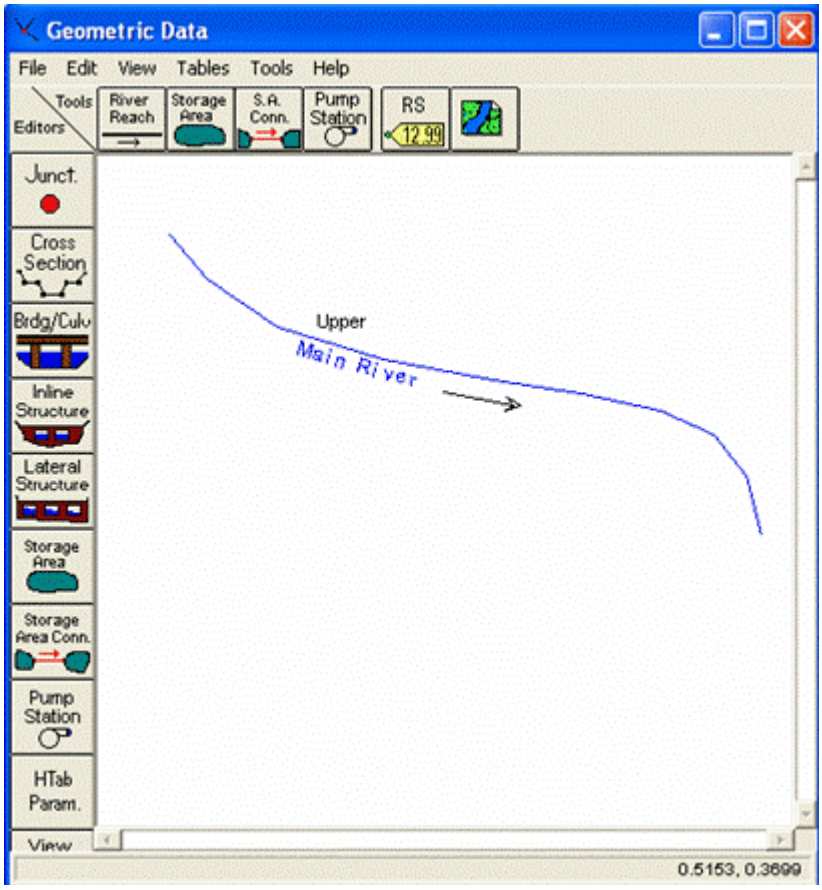


Figure 4 Geometric data window with "Main River" reach drawn

The next step is to enter cross section data. This is done by pressing the **Cross Section** button on the Geometric Data window shown in Figure 4. Once this button is pressed the Cross Section Data Editor will appear as shown in Figure 5.

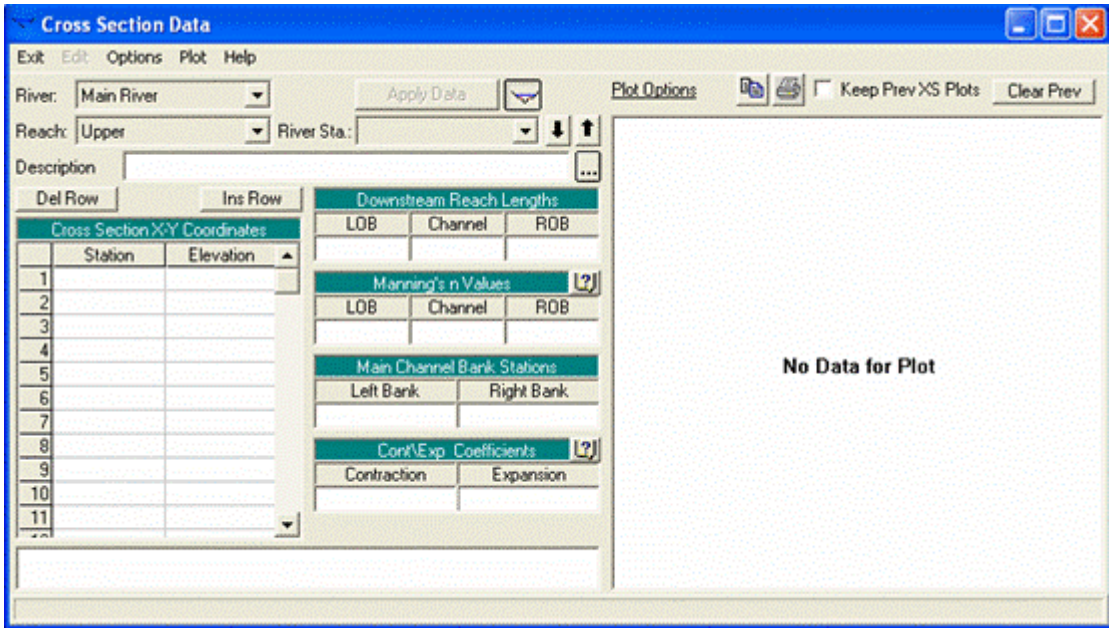


Figure 5 Cross Section Data Editor

All the data you need is included in various Worksheets in an Excel spreadsheet called "HEC_RAS_Example_data.xls". To enter the cross section data do the following:

1. Open the HEC_RAS_Example_data.xls spreadsheet. In the "Main River – Cross-section data" Worksheet you will find all the data you need.

2. In the Cross Section Editor window (shown in Figure 5) go to the **Options** window and **Add a new Cross section**. An input box will appear to prompt you to enter a **River Station Identifier**. This must have a numeric value. This numeric value describes where each cross section is located relative to each other within a reach. Cross sections are located from upstream (the river station with the highest numeric value) to downstream (the lowest river station). In the spreadsheet the **River Stations** are number **1.9** to **1.1**. Enter the upstream cross section first (River Station 1.9) as shown in Figure 6.

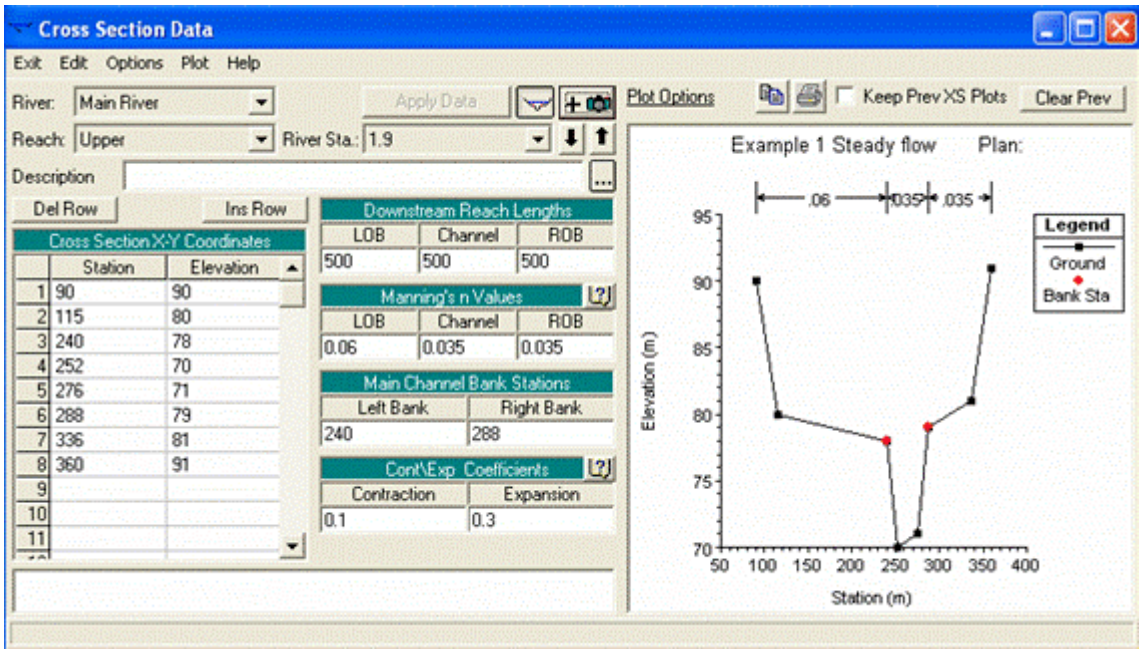


Figure 6 Cross section data entered for River Station 1.9

3. Once all the data has been entered press the Apply Data button. This button is used to tell the interface that you want the data to be accepted into memory. This button does not save the data to the hard disk. This can only be done from the **File menu** on the **Geometric Data Window**.

4. Plot the cross section to visually inspect the data. This is done by pressing the **Plot Cross Section** option under the **Plot** menu on the Cross Section Data Editor. The cross section should look the same as that shown in Figure 6.

5. Enter all the other cross sections with River Stations number 1.8 to 1.9 in the same way.

6. Once all the cross sections have been entered save the data to a file before continuing. Saving the data is done by selecting the **Save Geometry Data As** option from the **File** menu. After selecting this option you will be prompted to enter a Title for the geometric data. Enter **Existing river geometry** for this example then press the **OK** button – see Figure 7. A file name is automatically assigned to the geometry data based on what you have entered for the file name.

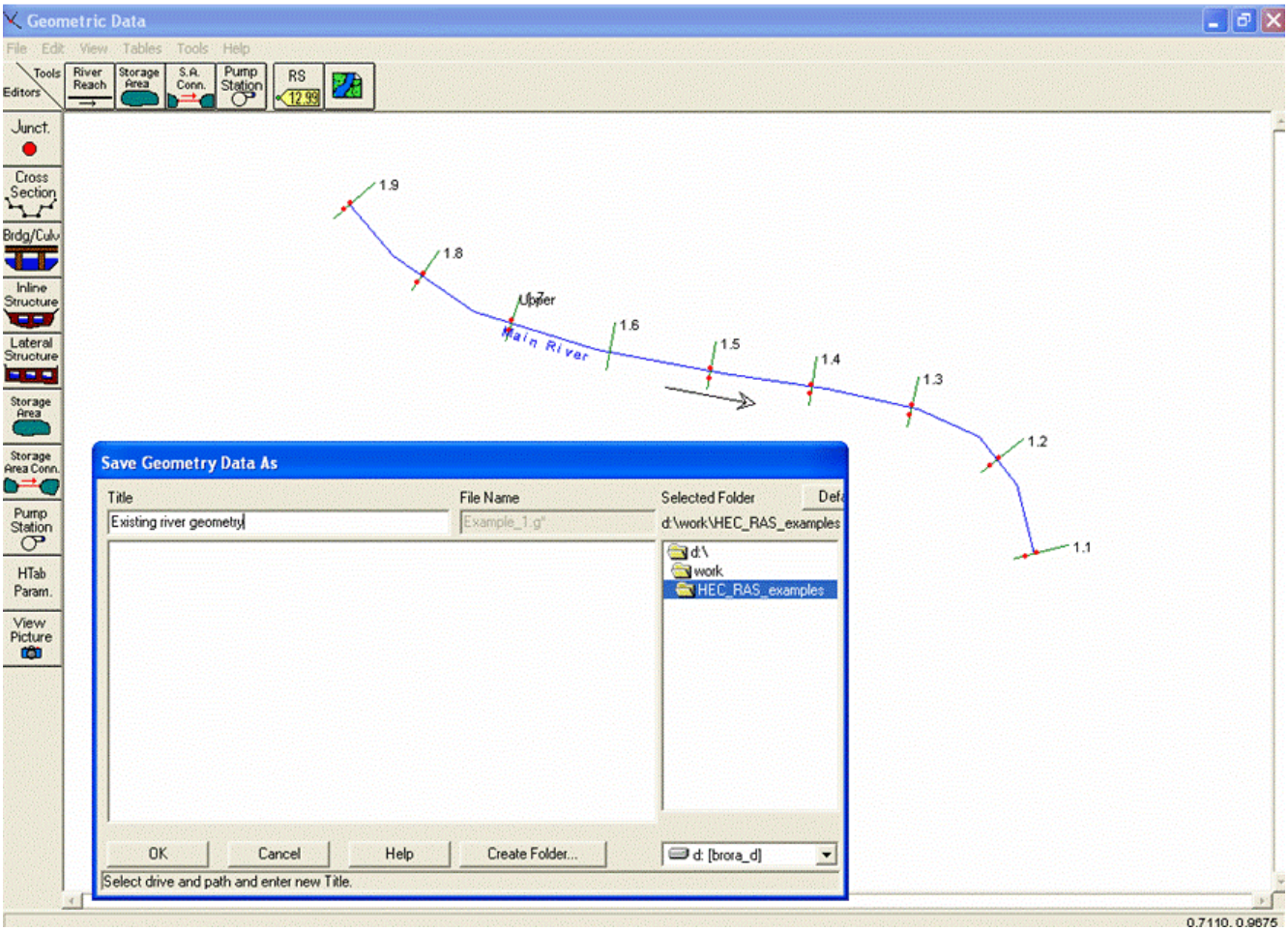


Figure 7 Saving the Geometry Data

The next step in developing the required data to perform steady flow water surface profile calculations is to enter the steady flow data. To bring up the steady flow data editor, select **Steady Flow Data** from the **Edit** menu on the HEC-RAS main window. A window should appear as shown in Figure 8.

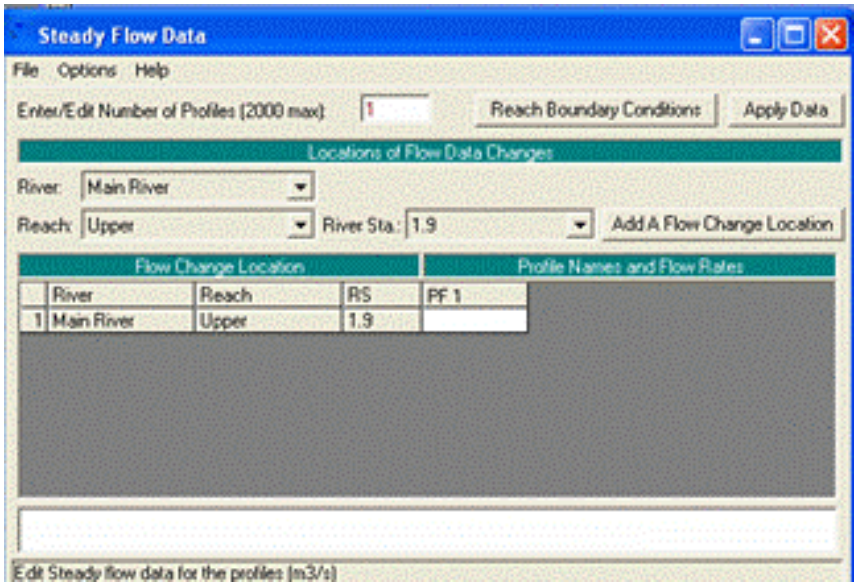


Figure 8 Steady Flow Data Editor

The first piece of information to enter is the number of profiles to be calculated. For Example 1 we are going to calculate 3 profiles. Enter the number "3" in the "Enter/Edit Number of Profiles" box as shown in Figure 9.

The next step is to enter the flow data. Flow data is entered from upstream to downstream for a reach. At least one flow rate must be entered for each reach in the river system. Once a flow value is entered at the upstream end of a reach it is assumed that the flow remains constant until another flow value is encountered within the reach. Additional flow values can be entered at any cross section location within the reach.

In Example 1 we will model the 1 in 10, 1 in 50 and 1 in 100 year flows. These will be entered at cross section 1.9, enter these as 500, 900 and 1600 m^3/s respectively. The profile labels will default to "PF#1", "PF#2" etc. Change these by choosing the **Edit Profile Names** from the **Options** menu within the Steady Flow Data Editor. Change the profile names to "1 in 10 year", "1 in 50 year" and "1 in 100 year" as shown in Figure 9, to represent the statistical return period of each of the events being modelled.

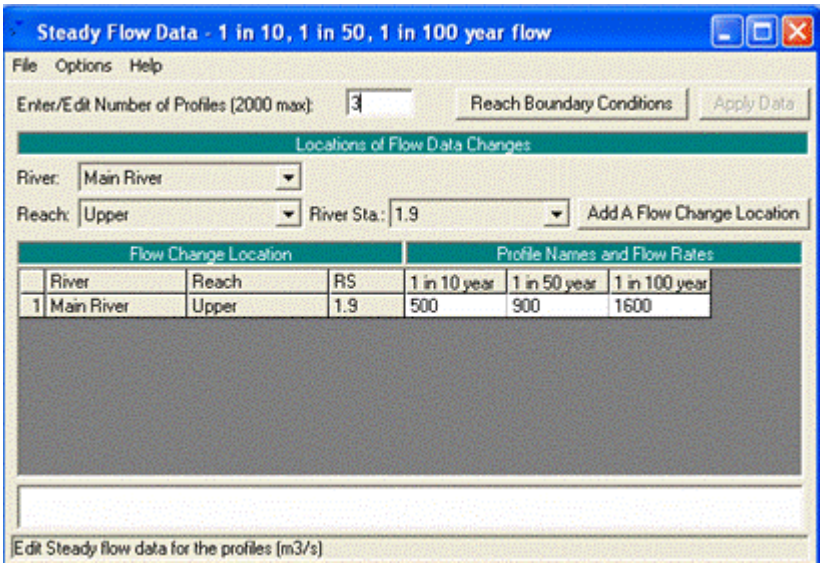


Figure 9 Steady Flow Data Editor with flows entered and profile names changed

The next step is to enter any required boundary conditions. To enter the boundary conditions, press the **Reach Boundary Conditions** button at the top of the Steady Flow Data editor. The boundary conditions editor will appear as shown in Figure 10, except yours will be blank the first time you open it.

Boundary conditions are necessary to establish the starting water surface at the ends of the river system. A starting water surface is necessary in order for the HEC RAS program to begin the calculations. In a subcritical flow regime, boundary conditions are only required at the downstream end of the river system. If a supercritical flow regime is going to be calculated, boundary conditions are only necessary at the upstream end of the river system. If a mixed flow regime calculation is going to made, then boundary conditions must be entered at all open ends of the river system.

In this example it is assumed that the flow is subcritical throughout the river system. Therefore, it is only necessary to enter a boundary condition at the downstream end of the Main River. Boundary conditions are entered by first selecting the cell in which you wish to enter the boundary condition. Then the type of boundary condition is selected from the four available types listed above the table. The four types of boundary conditions are:

- Known water surface elevations;
- Critical depth;
- Normal depth;
- Rating curve.

For this example, use the normal depth boundary condition. Once you have selected the cell for the downstream end of the Main River, press the **Normal Depth** button. A pop up box will appear requesting you to enter an average energy slope at the downstream end of the river, see Figure 10. Enter a value of 0.0004 (m/m) then press the **Enter** key. This completes all the boundary condition data. Press the **OK** button on the Boundary Conditions form to accept the data.

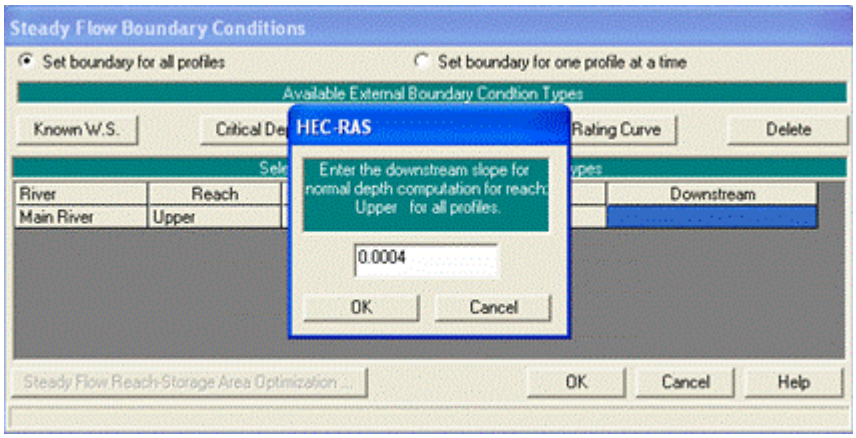


Figure 10 Steady Flow Boundary conditions

The last step in developing the steady flow data is to save the data to a file. To save the data, select the **Save Flow Data As** option from the **File** menu on the Steady Flow Data Editor. A pop up box will prompt you to enter a description of the flow data as shown in Figure 11. For this example enter "Existing conditions – steady flow". Once the data is saved, you can close the Steady Data editor.

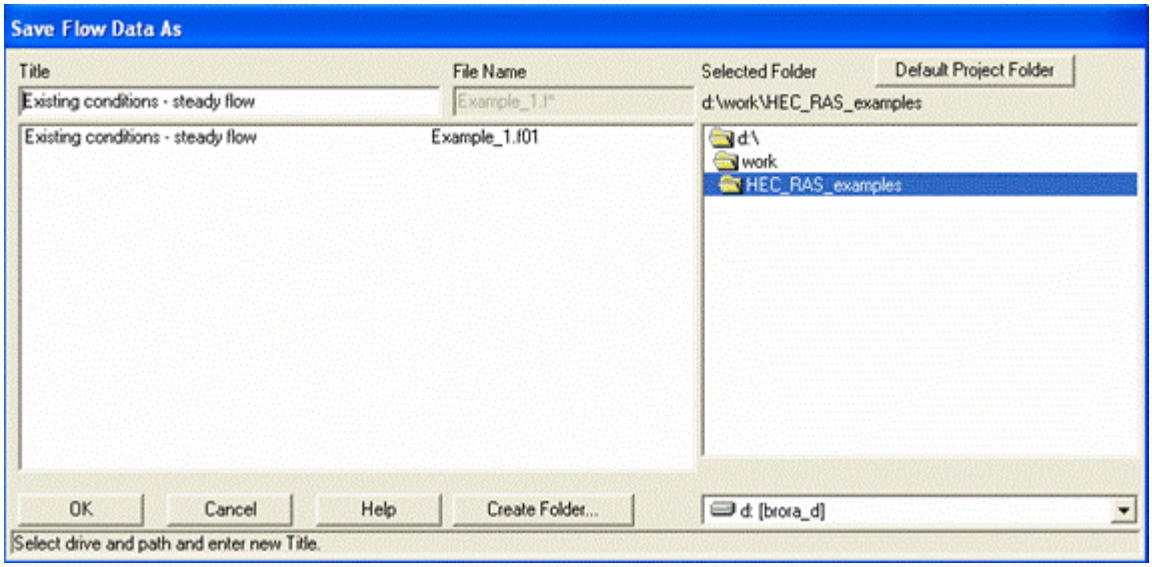


Figure 11 Saving the flow data

Now that all the data has been entered we can calculate the steady water profiles. To perform the simulations go to the HEC-RAS main window and select **Steady Flow Analysis** from the **Run** menu. The Steady Flow Analysis window should appear as shown in Figure 12 except yours will not have any plan titles yet.

The first step is to put together a **Plan**. The Plan defines which geometry and flow data are to be used, as well as providing a title and short identifier for the run. To establish a plan, select **New Plan** from the **File** menu on the Steady Flow Analysis window. Enter the plan title as "Existing Conditions Run" and then press the **OK** button. You will then be prompted to enter a short identifier. Enter a title of "Existing" in the **Short ID** box.

The next step is to select the desired flow regime for which the model will perform calculations. For this example we will be performing **Subcritical** flow calculations. Make sure that **Subcritical** is the selected flow regime. Saving the plan information is done by selecting the **Save Plan** from the **File** menu of the Steady Flow Analysis window.

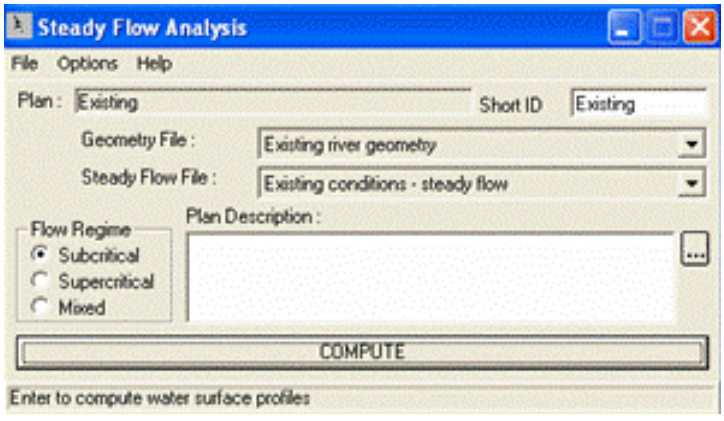


Figure 12 Steady Flow Analysis Simulation Window

Now that everything has been set, the steady flow computations can be performed by pressing the Compute button at the bottom of the Steady Flow Analysis Simulation window. Once the compute button has been pressed a separate window will appear showing you the progress of the computations. Once the computations have been completed, the computation window can be closed by double clicking the left corner of the window. At this time the Steady Flow Simulation window can also be closed.

Once the model has finished all of the computations successfully, you can begin viewing the results. Several output options are available from the **View** menu bar on the HEC RAS main window including:

- Create section plots;
- Profile plots;
- General plots;
- Rating curves;
- X-Y-Z perspective plots;
- Detailed tabular output at specific cross section (cross section table);
- Limited tabular output at many cross-sections.

Let's start by plotting a cross section. Select **Cross Sections** from the **View** menu bar on the HEC-RAS main window. This will automatically bring up a plot of the first cross section on the Main River (number 1.9), see Figure 13. You can also step through the plots by using the up and down arrow buttons. Several plotting features are available from the **Options** menu bar on the cross section plot window. These options include: zoom in; zoom out; selecting which plans, profiles and variables to plot; and control over lines, symbols, labels, scaling and grid options.

From the **Options** menu on the cross section editor select the **Profiles** option. Select the three available profiles as shown in Figure 13. Select different cross sections to plot and practise using some of the features available under the **Options** menu bar.

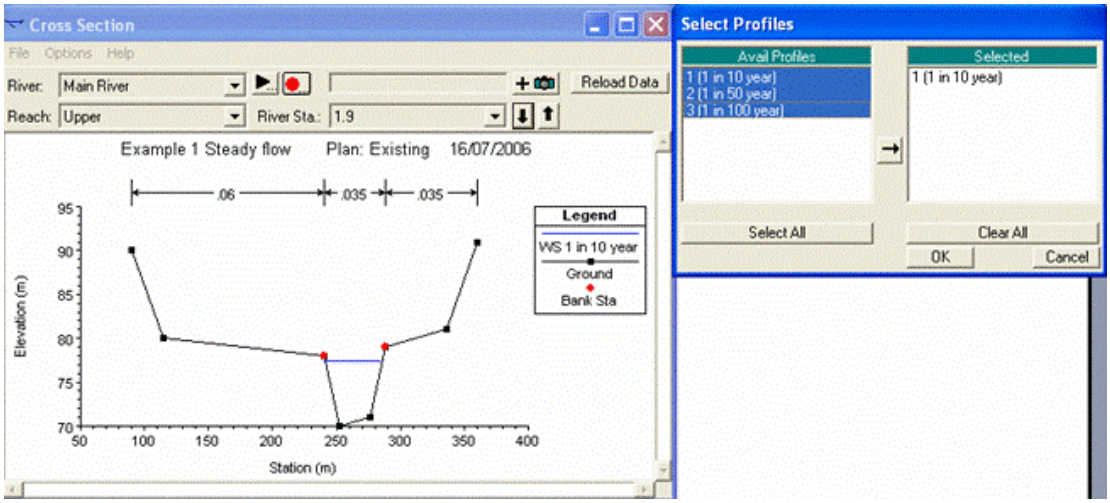


Figure 13 Cross section plot and the selection of profiles

Next plot a water surface profile. Select **Water Surface Profiles** from the **View** menu bar on the HEC-RAS main window. From the **Options** menu on the cross section editor select the **Profiles** option. Select the three available profiles. This will bring up a water surface profiles for the 1 in 10, 1 in 50 and 1 in 100 year floods for the Main River as shown in Figure 14.

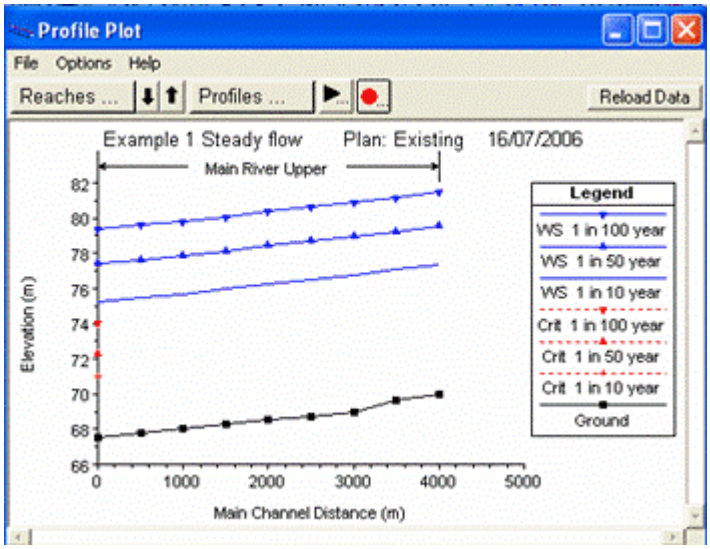


Figure 14 Profile plot for Main River

Next plot a computed rating curve. Select **Rating Curves** from the **View** menu on the HEC-RAS main window. A rating curve based on the computed water surface profiles will appear for the first cross section on the Main River as shown in Figure 15. You can look at the computed rating curve for any location by selecting the appropriate river, reach and river station from the list boxes at the top of the plot. Plotting options similar to the cross section and profile plots are available for the rating curve plots. Plot rating curves for various locations and practise using the available plotting options.

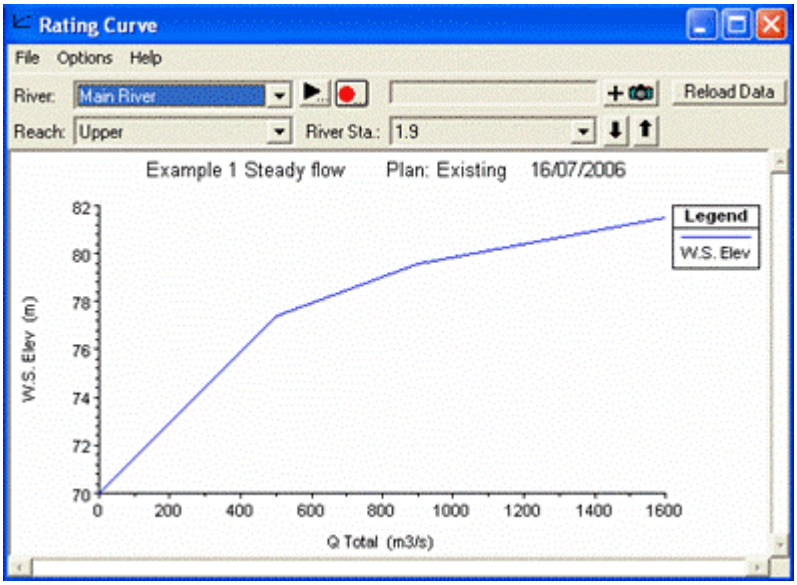


Figure 15 Computed rating curve for River Station 1.9 for Main River

Next look at an X-Y-Z Perspective Plot of the river system. From the **View** menu bar on the HEC-RAS main menu, select **X-Y-Z Perspective Plots**. A multiple cross section perspective should appear on the screen as shown in Figure 16. Try rotating the perspective view in different directions.

Now look at the tabular output. Go to the **View** menu bar on the HEC-RAS main window. There are two types of table available, a detailed output table and a profile summary table. Select **Detailed Output Tables** to get the first table to appear. The table should look like the one in Figure 17. This table shows detailed hydraulic information at a single cross sections.

Now bring up the profile summary table. This table shows a limited number of hydraulic variables for several cross sections. There are several types of profile tables listed under the **Std. Tables** menu bar of the profile table window. Some of the tables are designed to provide specific information at hydraulic structures (e.g. bridges and culverts), while others provide generic information at all cross sections. From the **View** menu select the **Profile Summary Table** option. A table similar to that shown in Figure 18 should appear. Open a new Excel spreadsheet file. From the **File** menu in the Profile Output Table window select the **Copy to Clipboard (Data and Headings)** option. In the Excel spreadsheet you have opened select the paste options and save the spreadsheet as Example_1_results.xls.

You have now completed the first example.

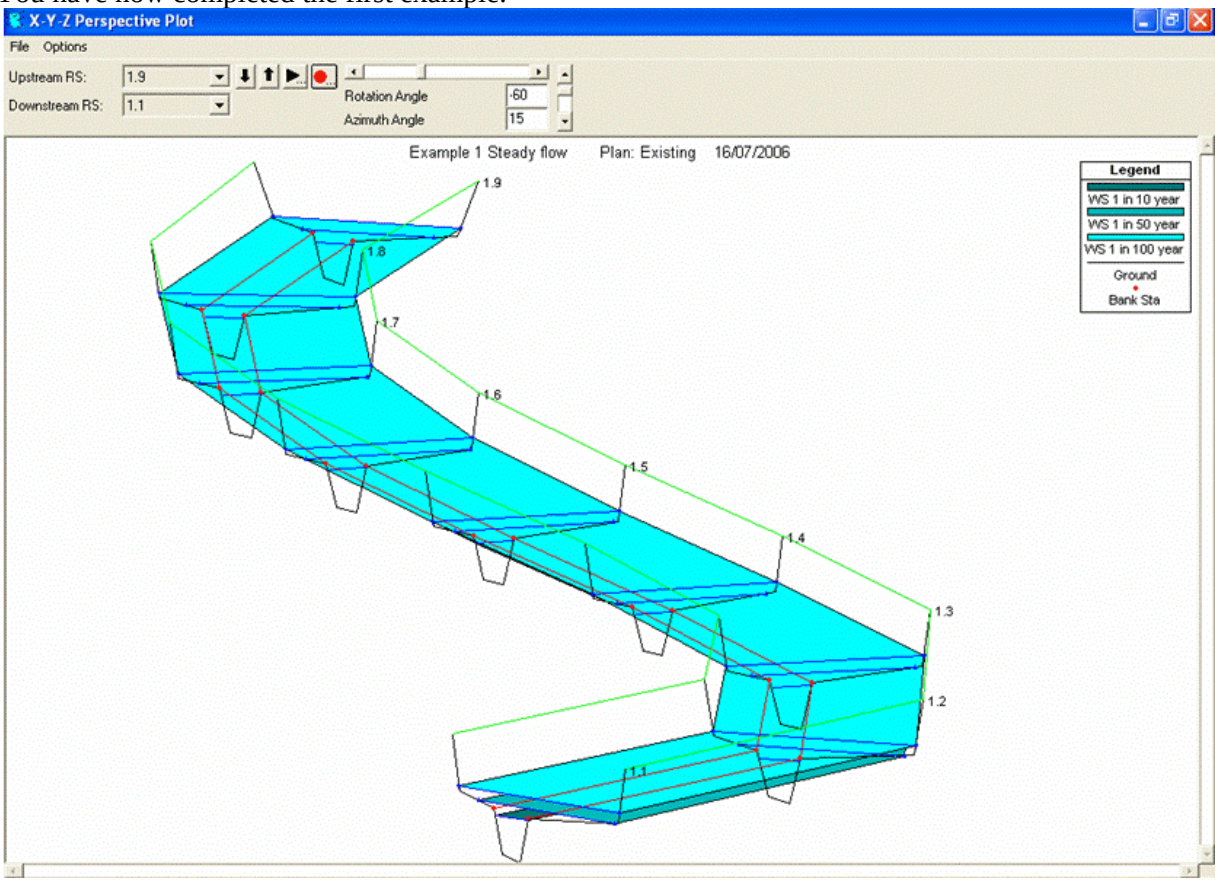


Figure 16 X-Y-Z perspective of the Main River

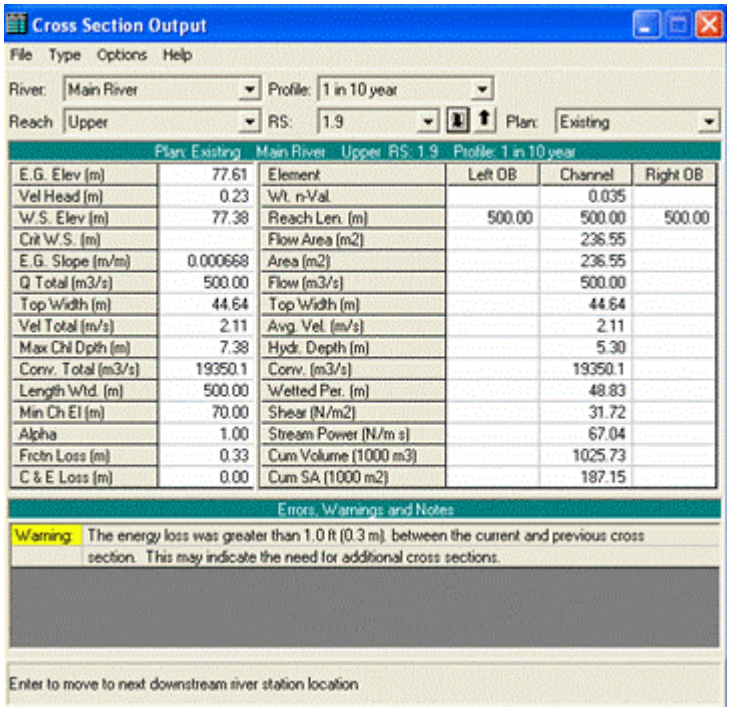
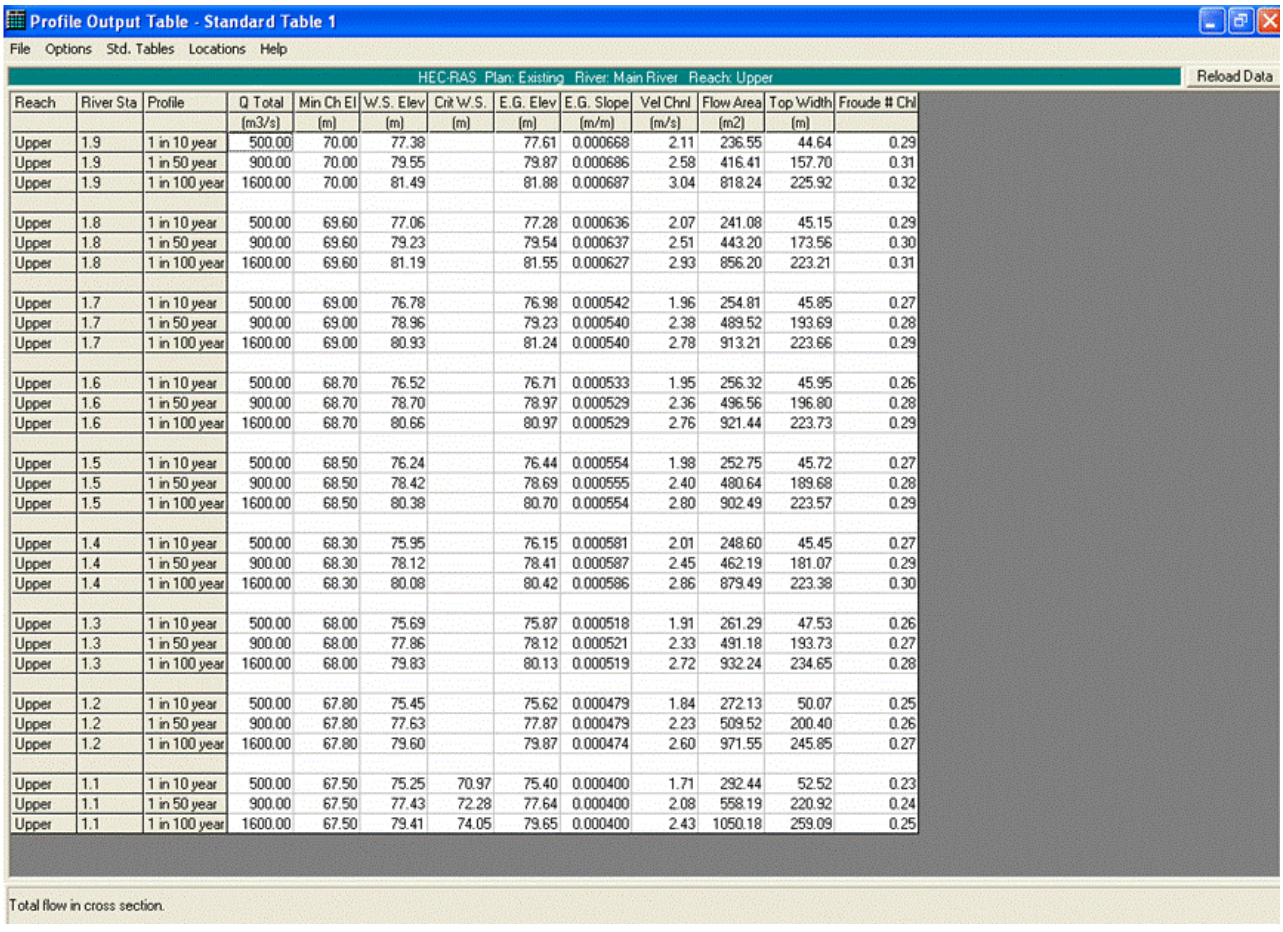

Cross Section Output
File Type Options Help
River: Main River
Profile: 1 in 10 year
Reach Upper
RS: 1.9
Plan: Existing
Plan: Existing Main River Upper RS: 1.9 Profile: 1 in 10 year
E.G. Elev (m) 77.61
Vel Head (m) 0.23
W.S. Elev (m) 77.38
Crit W.S. (m)
E.G. Slope (m/m) 0.000668
Q Total (m3/s) 500.00
Top Width (m) 44.64
Vel Total (m/s) 2.11
Max Chl Dpth (m) 7.38
Conv. Total (m3/s) 19350.1
Length Wtd. (m) 500.00
Min Ch El (m) 70.00
Alpha 1.00
Frctn Loss (m) 0.33
C & E Loss (m) 0.00
Element Left OB Channel Right OB
Wt. n-Val. 0.035
Reach Len. (m) 500.00 500.00 500.00
Flow Area (m2) 236.55
Area (m2) 236.55
Flow (m3/s) 500.00
Top Width (m) 44.64
Avg. Vel. (m/s) 2.11
Hydr. Depth (m) 5.30
Conv. (m3/s) 19350.1
Wetted Per. (m) 48.83
Shear (N/m2) 31.72
Stream Power (N/m s) 67.04
Cum Volume (1000 m3) 1025.73
Cum SA (1000 m2) 187.15
Errors, Warnings and Notes
Warning: The energy loss was greater than 1.0 ft (0.3 m) between the current and previous cross section. This may indicate the need for additional cross sections.
Enter to move to next downstream river station location

Figure 17 Detailed tabular output at a cross section


Profile Output Table - Standard Table 1
File Options Std. Tables Locations Help
HEC-RAS Plan: Existing River: Main River Reach: Upper
Reload Data
Total flow in cross section.

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(m3/s)	(m)	(m)	(m)	(m)	(m/m)	(m/s)	(m2)	(m)	
Upper	1.9	1 in 10 year	500.00	70.00	77.38		77.61	0.000668	2.11	236.55	44.64	0.29
Upper	1.9	1 in 50 year	900.00	70.00	79.55		79.87	0.000686	2.58	416.41	157.70	0.31
Upper	1.9	1 in 100 year	1600.00	70.00	81.49		81.88	0.000687	3.04	818.24	225.92	0.32
Upper	1.8	1 in 10 year	500.00	69.60	77.06		77.28	0.000636	2.07	241.08	45.15	0.29
Upper	1.8	1 in 50 year	900.00	69.60	79.23		79.54	0.000637	2.51	443.20	173.56	0.30
Upper	1.8	1 in 100 year	1600.00	69.60	81.19		81.55	0.000627	2.93	856.20	223.21	0.31
Upper	1.7	1 in 10 year	500.00	69.00	76.78		76.98	0.000542	1.96	254.81	45.85	0.27
Upper	1.7	1 in 50 year	900.00	69.00	78.96		79.23	0.000540	2.38	489.52	193.69	0.28
Upper	1.7	1 in 100 year	1600.00	69.00	80.93		81.24	0.000540	2.78	913.21	223.66	0.29
Upper	1.6	1 in 10 year	500.00	68.70	76.52		76.71	0.000533	1.95	256.32	45.95	0.26
Upper	1.6	1 in 50 year	900.00	68.70	78.70		78.97	0.000529	2.36	496.56	196.80	0.28
Upper	1.6	1 in 100 year	1600.00	68.70	80.66		80.97	0.000529	2.76	921.44	223.73	0.29
Upper	1.5	1 in 10 year	500.00	68.50	76.24		76.44	0.000554	1.98	252.75	45.72	0.27
Upper	1.5	1 in 50 year	900.00	68.50	78.42		78.69	0.000555	2.40	480.64	189.68	0.28
Upper	1.5	1 in 100 year	1600.00	68.50	80.38		80.70	0.000554	2.80	902.49	223.57	0.29
Upper	1.4	1 in 10 year	500.00	68.30	75.95		76.15	0.000581	2.01	248.60	45.45	0.27
Upper	1.4	1 in 50 year	900.00	68.30	78.12		78.41	0.000587	2.45	462.19	181.07	0.29
Upper	1.4	1 in 100 year	1600.00	68.30	80.08		80.42	0.000586	2.86	879.49	223.38	0.30
Upper	1.3	1 in 10 year	500.00	68.00	75.69		75.87	0.000518	1.91	261.29	47.53	0.26
Upper	1.3	1 in 50 year	900.00	68.00	77.86		78.12	0.000521	2.33	491.18	193.73	0.27
Upper	1.3	1 in 100 year	1600.00	68.00	79.83		80.13	0.000519	2.72	932.24	234.65	0.28
Upper	1.2	1 in 10 year	500.00	67.80	75.45		75.62	0.000479	1.84	272.13	50.07	0.25
Upper	1.2	1 in 50 year	900.00	67.80	77.63		77.87	0.000479	2.23	509.52	200.40	0.26
Upper	1.2	1 in 100 year	1600.00	67.80	79.60		79.87	0.000474	2.60	971.55	245.85	0.27
Upper	1.1	1 in 10 year	500.00	67.50	75.25	70.97	75.40	0.000400	1.71	292.44	52.52	0.23
Upper	1.1	1 in 50 year	900.00	67.50	77.43	72.28	77.64	0.000400	2.08	558.19	220.92	0.24
Upper	1.1	1 in 100 year	1600.00	67.50	79.41	74.05	79.65	0.000400	2.43	1050.18	259.09	0.25

Figure 18 Tabular output in summary table format

Exercise 2 Adding a bridge to the steady flow river model with a

If the Example_1 project is not still open from your previous work re-open it. When you have re-opened it go to the **File** menu on the main window and select **Save Project As**. In the **Title** box enter "**Example 2 Steady Flow with bridge added**" and in the File Name box enter "**Example_2.prj**". Note it is important that you check under the **Options** menu that the **Unit System** is set to **SI** (i.e. Standard International or metric units).

The purpose of this exercise is to add a bridge to the steady flow that you set up in Exercise 1. A proposed bridge is to be located just downstream of the cross section with the Station Label 1.6.

The first step is to select the **Geometric Data** from the **Edit** menu on the HEC-RAS main menu. Once this option is selected the geometric data window will appear as shown in Figure 1.

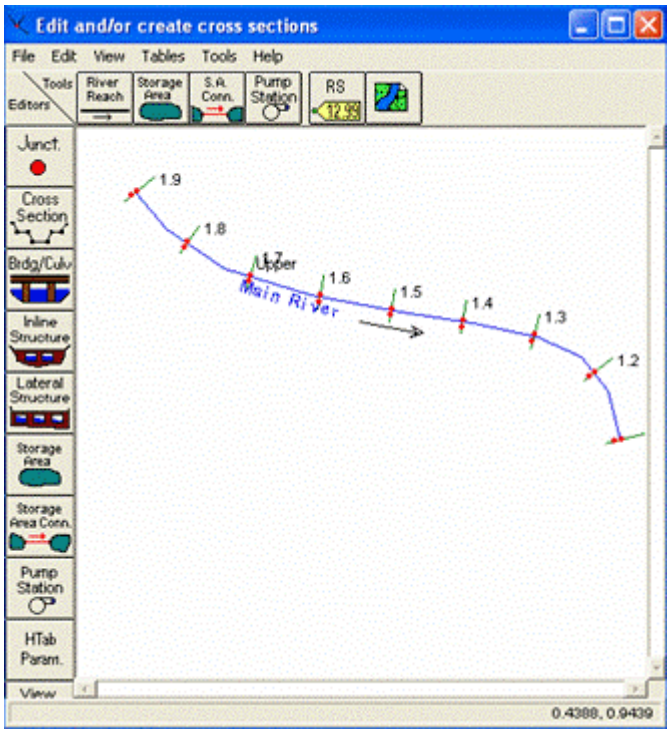


Figure 1 Geometric data window

The proposed bridge is to be located 30 m downstream of the cross section labelled 1.6. The first set is to add an additional cross-section to your model and alter their properties according. Open the Excel spreadsheet called "**HEC_RAS_Example_data.xls**". There is a Worksheet entitled "**Bridge –Data**". This includes all the additional data that you will need to add the proposed bridge to your model.

To enter an additional cross section data press the **Cross Section** button on the **Geometric Data window**. Once this button is pressed the **Cross Section Data Editor** will appear as shown in Figure 2.

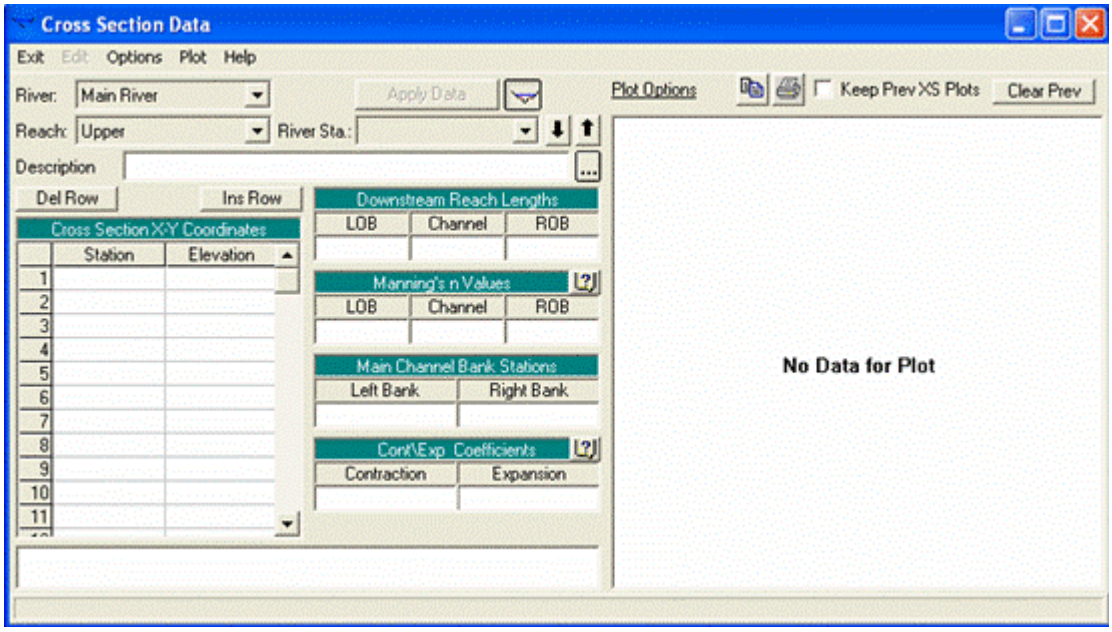


Figure 2 Cross Section Data Editor

In the Cross Section Editor window (shown in Figure 2) go to the **Options** window and **Add a new Cross section**. An input box will appear to prompt you to enter a **River Station Identifier**. This must have a numeric value. This numeric value describes where each cross section is located relative to each other within a reach. Cross sections are located from upstream (the river station with the highest numeric value) to downstream (the lowest river station).

The new cross-section that you will add to the model will be labelled **1.51**. Add the cross-section data from the Excel spreadsheet called "HEC_RAS_Example_data.xls" in the Worksheet entitled "Bridge – Data". In order not to extend the total length of the river when you have entered the new cross section you will need to change the "**Downstream Channel Reach Lengths**" for the cross section with the station label 1.6. Open cross section 1.6 and change the "Downstream Reach Lengths" for the "**LOB**", "**Channel**" and "**ROB**" from 500 to 30 as shown in Figure 3.

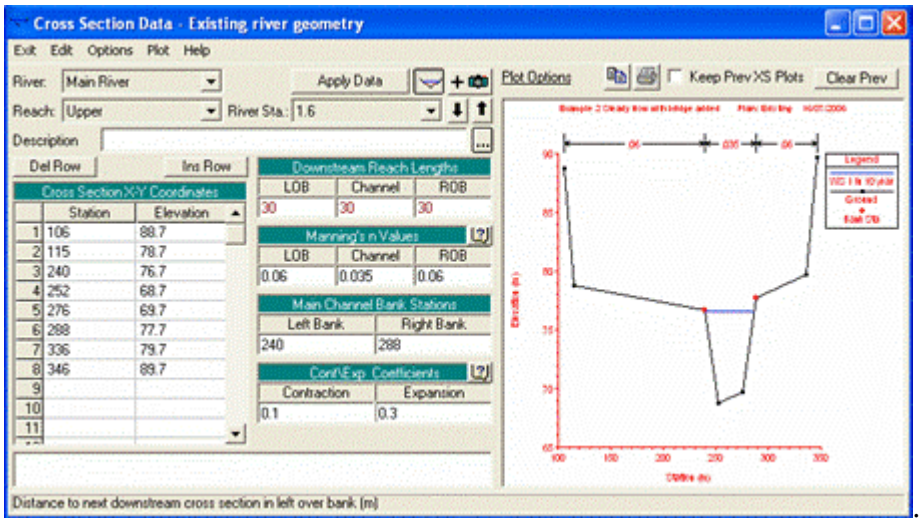


Figure 3 Changing downstream reach lengths in cross section 1.6

The required information for a bridge consists of: the river, reach and river station identifiers; a short description of the bridge; bridge abutments (if they exist); bridge piers (if the bridge has piers); and specifying the bridge modelling approach.

To add a bridge to the model do the following:

1. The first step is to return to the **Geometric Data Window** and click on the "**Bridge/Culvert**" button. A window similar to that shown in Figure 4 should appear.

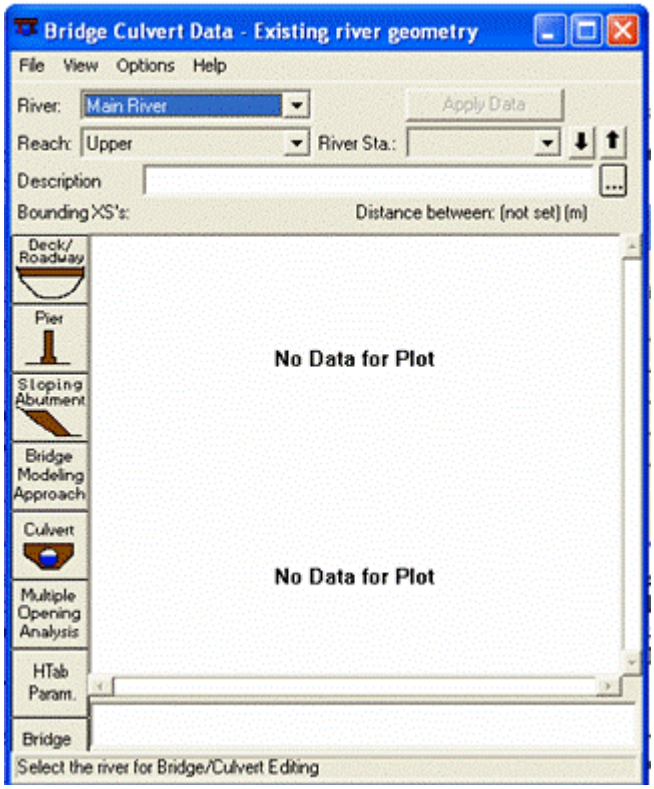


Figure 4 Bridge Culvert Data window

2. Go to the **Options** menu and select **Add a Bridge and/or Culvert** from the list. An input box will appear prompting you to enter a river station identifier for the new bridge. Add the station identifier **1.55**. Remember the River Station tag or identifier defines where the bridge will be identified within a specific reach. The river station tag does not have to be an actual river station of the bridge but it must be a numeric value. The river station tag for the bridge should be numerically between the two cross sections that bound the bridge.

3. The data for the geometry of the proposed bridge now needs to be entered. The bridge geometry is defined by the following:

   - The deck/roadway;
   - Number of piers (optional) – note the bridge we will be modelling has no piers;
   - Sloping Abutments (optional;
   - Bridge modelling approach information.

   First enter the **Deck/Roadway** geometry. Click on the "**Deck/Roadway**" button in the **Bridge/Culvert Editor**. A window similar to that shown in Figure 5 should open although it will initially contain no data. The data for the Deck/Roadway of the bridge is in the Excel Spreadsheet called "HEC_RAS_Example_data.xls" in the Worksheet entitled "Bridge – Data". Once you have entered all the data your Deck/Roadway editor should appear as in Figure 6.

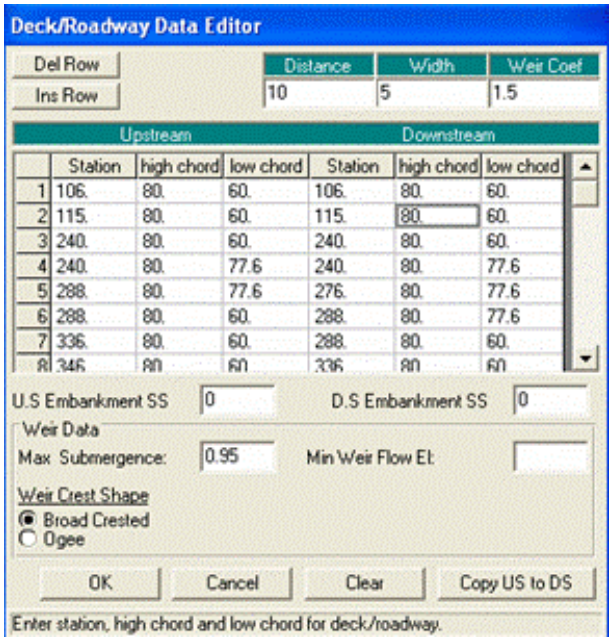


Figure 5 Deck/Roadway Data Editor

The **Distance** you have entered in the Deck/Roadway editor is the distance between the upstream side of the bridge deck and the cross section immediately upstream of the bridge.

The **Width** field is used to enter the width of the bridge deck along the stream.

The **Weir Coefficient** is the coefficient that will be used for weir flow over the bridge deck in the standard weir equation.

The **Upstream Stationing, High Chord and Low Chord** define the geometry of the bridge deck on the upstream side of the bridge.

The **Downstream Stationing, High Chord and Low Chord** define the geometry of the bridge deck on the upstream side of the bridge. For most bridges this will be the same as the upstream information.

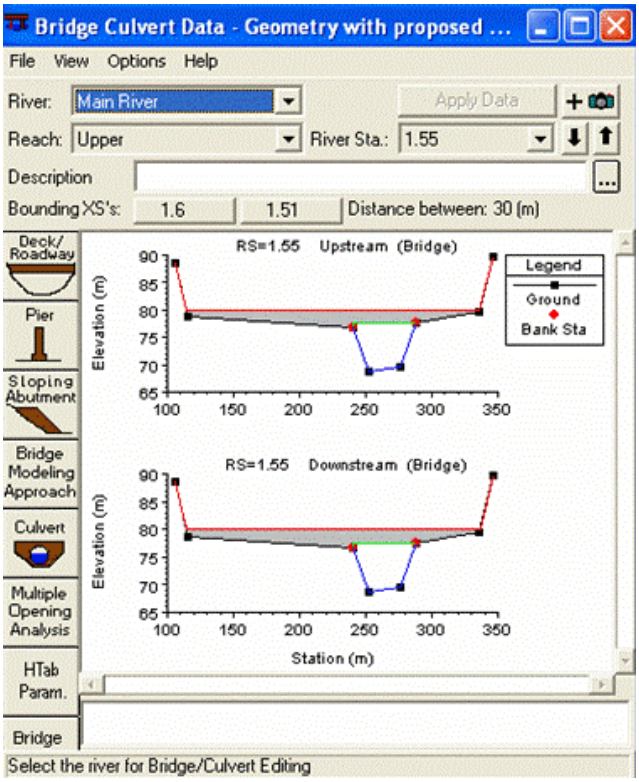


Figure 6 Deck/Roadway Data Editor once initial data entry has been completed

The **Bridge Modeling Approach** editor is used to define how the bridge will be modelled and to enter any coefficients that are necessary. To bring up the Bridge Modeling Approach editor press the **Bridge Modeling Approach** button on the **Bridge/Culvert Data Editor**. Once this button is pressed the editor will appear as shown in Figure 7 except yours will only have the default methods selected.

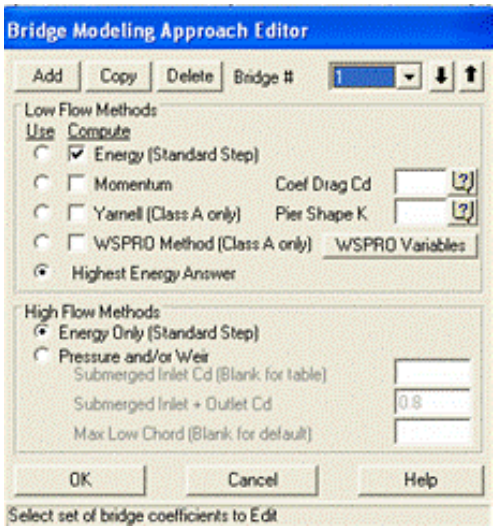


Figure 7 Bridge Modelling Approach Editor

There is no need to change the settings that are currently selected in the **Bridge Modeling Approach Editor**. Details of the various methods used to model bridges are available in the HEC-RAS model manuals.

The next step is to click on the HTAB Param button on the Bridge Modelling Approach Editor. The window shown in Figure 8 should pop up. Change the headwater maximum elevation to 80 as shown in Figure 8.

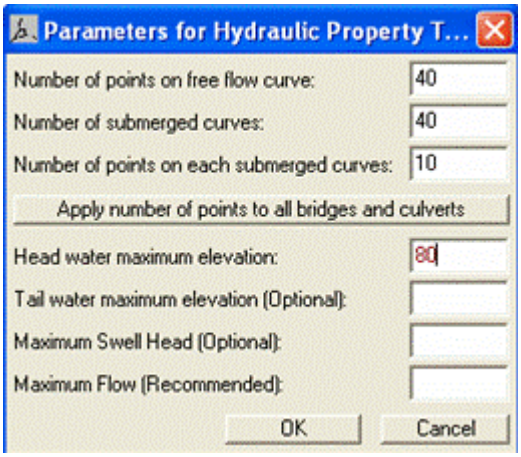


Figure 8 Parameters for Hydraulic Property Tables

The final step in modelling the bridge is to enter the **Ineffective Flow Areas** up and downstream of the bridge. The **Ineffective Flow Area Areas** are the areas that will contain water that is actually not being conveyed (ineffective flow). In this case the proposed bridge will be on an embankment and the effective flow area of the upstream and downstream cross sections (labelled **1.6** and **1.51**) will change).

Click on the **Bridge/Culvert button** in the **Geometry Data Editor** if it is not open already. At the top of the **Bridge/Culvert Data Editor** (see Figure 6) you will see the words **Bounding X's** and the River Stations **1.6** and **1.51**. Click on the river station 1.6 a popup box similar to that shown in Figure 9 should open.

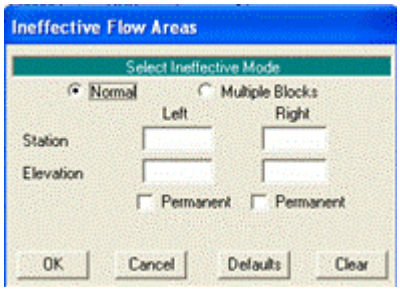


Figure 9 Ineffective Flow Areas Editor

Select "**Multiple Blocks**" a box similar to Figure 10 should open, although yours will have no data in it. Add the data for ineffective flow areas from the spreadsheet (this is also shown in Figure 8) and click the **Apply Data** button. Once you have done this do the same for cross section 1.51.

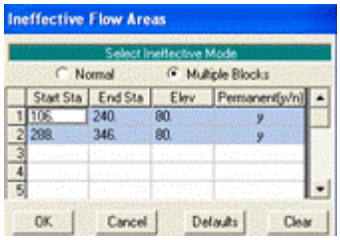


Figure 10 Ineffective Flow Areas Editor for Multiple Blocks

Finally go to the **HTAB** editor and change the **Headwater Maximum Elevation** to **81**.

Now close the Bridge Geometry Editor and go to the **File** menu in the Geometric Data Editor and go to **Save Geometry Data As**. Enter "**Geometry with proposed bridge**" as the title.

Now that all the data has been entered we can calculate the steady water profiles. To perform the simulations go to the HEC-RAS main window and select **Steady Flow Analysis** from the **Run** menu. The Steady Flow Analysis window should appear as shown in Figure 11 except yours will not have any plan titles yet.

The first step is to put together a **Plan**. The Plan defines which geometry and flow data are to be used, as well as providing a title and short identifier for the run. To establish a plan, select **New Plan** from the **File** menu on the Steady Flow Analysis window. Enter the plan title as "**Proposed bridge – steady flow**" and then press the **OK** button. You will then be prompted to enter a short identifier. Enter a title of "**BridgeSteady**" in the **Short ID** box.

The next step is to select the desired flow regime for which the model will perform calculations. For this example we will be performing **Subcritical** flow calculations. Make sure that **Subcritical** is the selected flow regime. Saving the plan information is done by selecting the **Save Plan** from the **File** menu of the Steady Flow Analysis window.

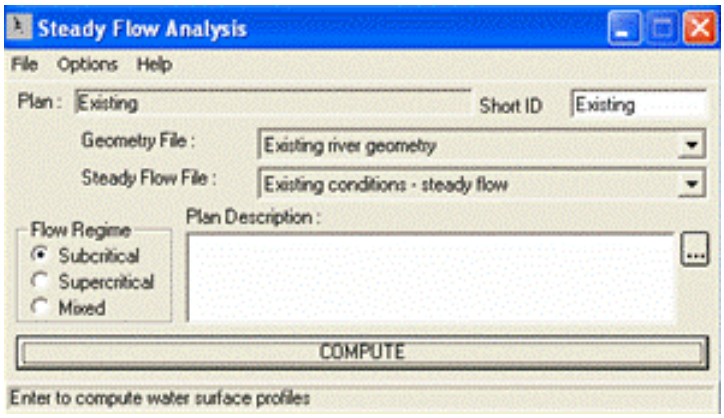


Figure 11 Steady Flow Analysis Simulation Window

Now that everything has been set, the steady flow computations can be performed by pressing the Compute button at the bottom of the Steady Flow Analysis Simulation window. Once the compute button has been pressed a separate window will appear showing you the progress of the computations. Once the computations have been completed, the computation window can be closed by double clicking the left corner of the window. At this time the Steady Flow Simulation window can also be closed.

Once the model has finished all of the computations successfully, you can begin viewing the results. Several output options are available from the **View** menu bar on the HEC RAS main window including:

- Create section plots;
- Profile plots;
- General plots;
- Rating curves;
- X-Y-Z perspective plots;
- Detailed tabular output at specific cross section (cross section table)
- Limited tabular output at many cross-sections.

Let's start by plotting a cross section. Select **Cross Sections** from the **View** menu bar on the HEC-RAS main window. This will automatically bring up a plot of the first cross section on the Main River (number 1.9), see Figure 12. You can also step through the plots by using the up and down arrow buttons. Several plotting features are available from the **Options** menu bar on the cross section plot window. These options include: zoom in; zoom out; selecting which plans, profiles and variables to plot; and control over lines, symbols, labels, scaling and grid options.

From the **Options** menu on the cross section editor select the **Profiles** option. Select the three available profiles. Select different cross sections to plot and practise using some of the features available under the **Options** menu bar.

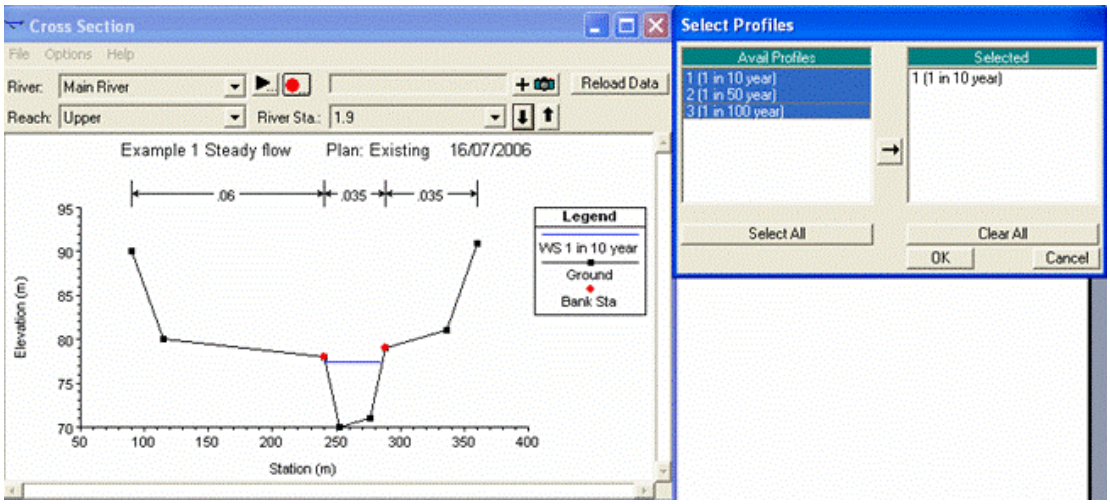


Figure 12 Cross section plot and the selection of profiles

Next plot a water surface profile. Select **Water Surface Profiles** from the **View** menu bar on the HEC-RAS main window. From the **Options** menu on the cross section editor select the **Profiles** option. Select the three available profiles. This will bring up a water surface profiles for the 1 in 10, 1 in 50 and 1 in 100 year floods for the Main River.

Next look at an X-Y-Z Perspective Plot of the river system. From the **View** menu bar on the HEC-RAS main menu, select **X-Y-Z Perspective Plots**. A multiple cross section perspective should appear on the screen. Try rotating the perspective view in different directions.

Now look at the tabular output. Go to the **View** menu bar on the HEC-RAS main window. There are two types of table available, a detailed output table and a profile summary table. Select **Detailed Output Tables** to get the first table to appear. This table shows detailed hydraulic information at a single cross sections.

Now bring up the profile summary table. This table shows a limited number of hydraulic variables for several cross sections. There are several types of profile tables listed under the **Std. Tables** menu bar of

the profile table window. Some of the tables are designed to provide specific information at hydraulic structures (e.g. bridges and culverts), while others provide generic information at all cross sections. From the **View** menu select the **Profile Summary Table** option. Open a new Excel spreadsheet file. From the **File** menu in the Profile Output Table window select the **Copy to Clipboard (Data and Headings)** option. In the Excel spreadsheet you have opened select the paste options and save the spreadsheet as **Example_2_results.xls**.

Compare the maximum water levels from Exercise 1 without the bridge to those that you get from Exercise 2 with the bridge in place. What is the difference in maximum water levels directly upstream of the bridge for the 1 in 100 year flood between the existing situation and when the proposed bridge is in place?

You have now completed the second example.

Exercise 3 Running an unsteady flow model with the proposed bridge in place

If the Example_2 project is not still open from your previous work re-open it. When you have re-opened it go to the **File** menu on the main window and select **Save Project As**. In the **Title** box enter "**Example 3 Unsteady flow with bridge"** and in the File Name box enter "**Example_3.prj**". Note it is important that you check under the **Options** menu that the **Unit System** is set to **SI** (i.e. Standard International or metric units).

The purpose of this exercise is to run the previous model you created with the proposed bridge with an unsteady flow i.e. a flow that varies with time.

The first step is to go to the **Edit** menu in the HEC RAS Main Window and select the Unsteady Flow Data Option. The **Unsteady Flow Data** editor shown in Figure 1 should open.

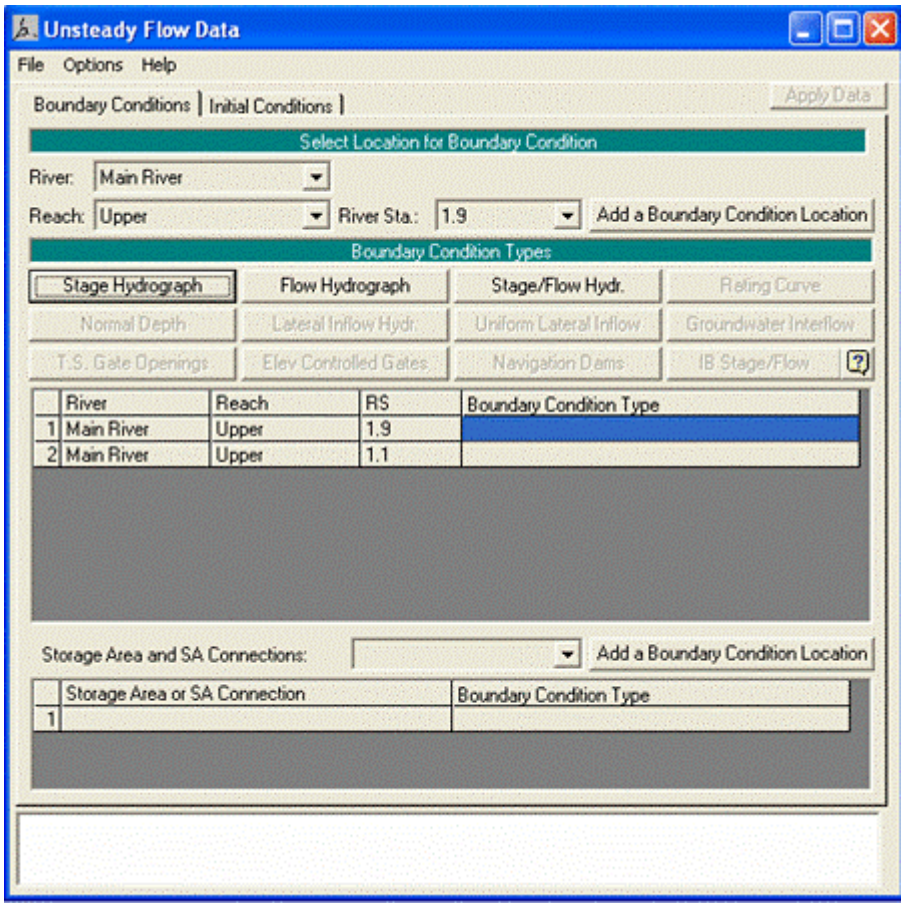


Figure 1 Unsteady flow data editor

For the Main River station labelled 1.9 select the **Flow Hydrograph** button shown in Figure 1. A new window should open as shown in Figure 2.

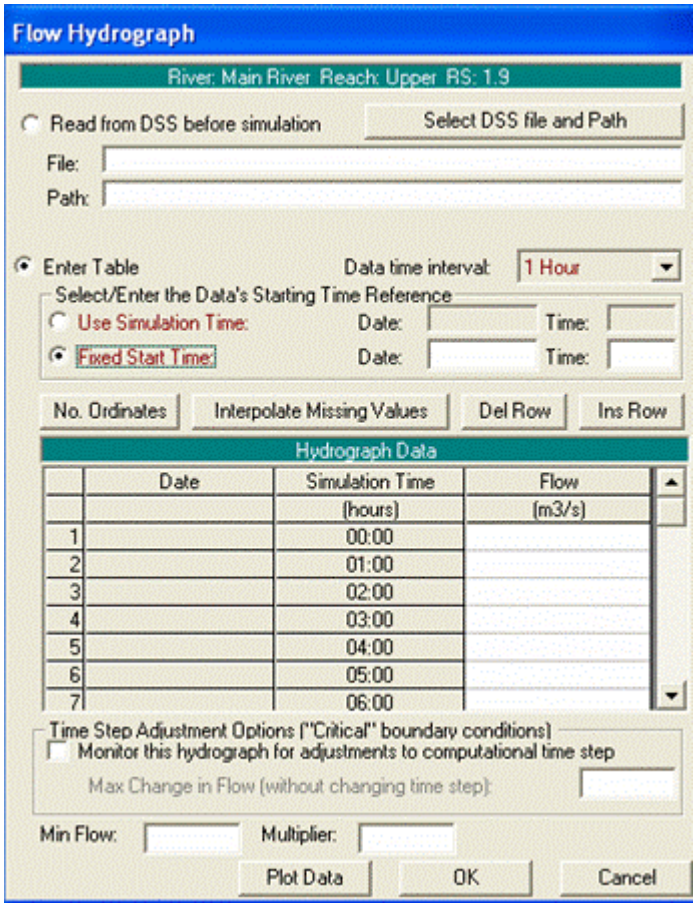


Figure 2 Flow hydrograph editor

In the Flow hydrograph editor select the following as shown in Figure 3.

- Data time interval of **15 Minute**;
- User Simulation Time – Add a date of **25Jul2006** and a time of **00:00**;
- Add the **1 in 100 year** flow data that is in the Excel spreadsheet called "**HEC_RAS_Example_data.xls**" in the Worksheet called "**Flow_hydrograph**".

The entered data is shown in Figure 3. Push the Plot Data button and a flow hydrograph similar to that shown in Figure 4 should appear on the screen.

A downstream boundary also needs to be entered at River Station 1.1. For this example, use the normal depth boundary condition. Once you have selected the cell for the downstream end of the Main River, press the **Normal Depth** button. A pop up box will appear requesting you to enter an average energy slope at the downstream end of the river. Enter a value of 0.0004 (m/m) then press the **Enter** key. This completes all the boundary condition data. Press the **OK** button on the Boundary Conditions form to accept the data.

For the model to run in an unsteady mode it needs some initial conditions. Now click on the **Initial Conditions** tab that is shown in Figure 1. A table will appear as shown in Figure 5. Add an initial flow of 130at River Station 1.9 and click the **Apply Data** button.

Now go to the **File** menu and select **Save Unsteady Data As**. In the **Title** box add the title **1 in 100 year flow**.

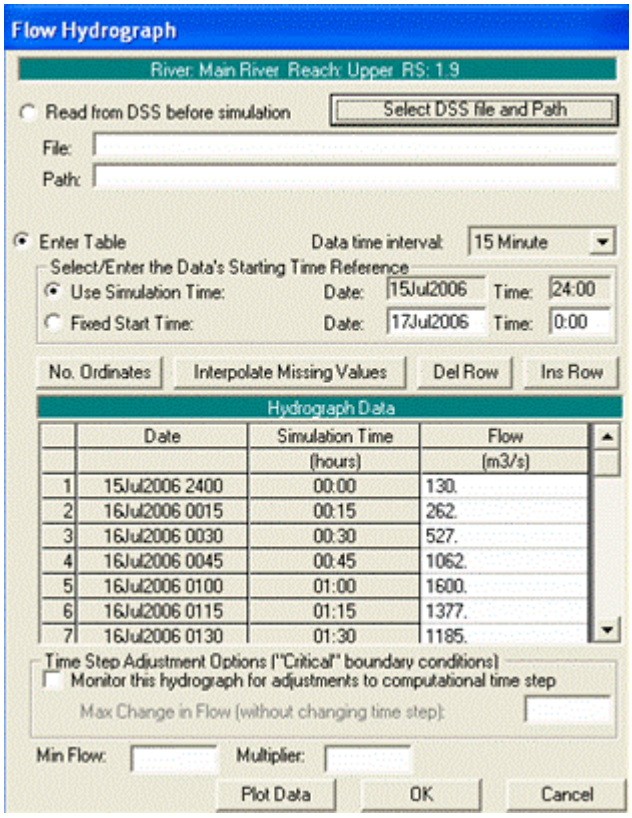


Figure 3 Flow hydrograph editor with data added

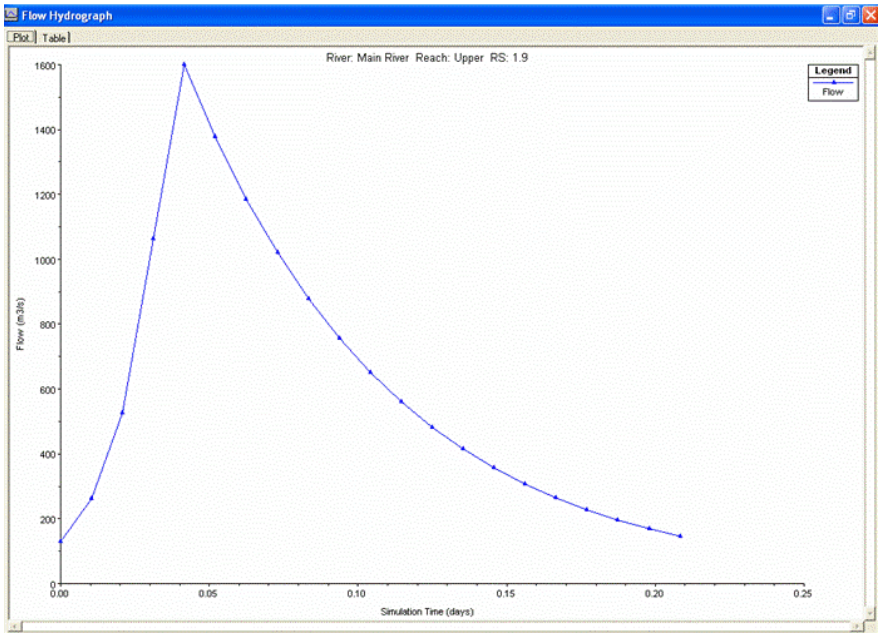


Figure 4 Plot of the flow hydrograph

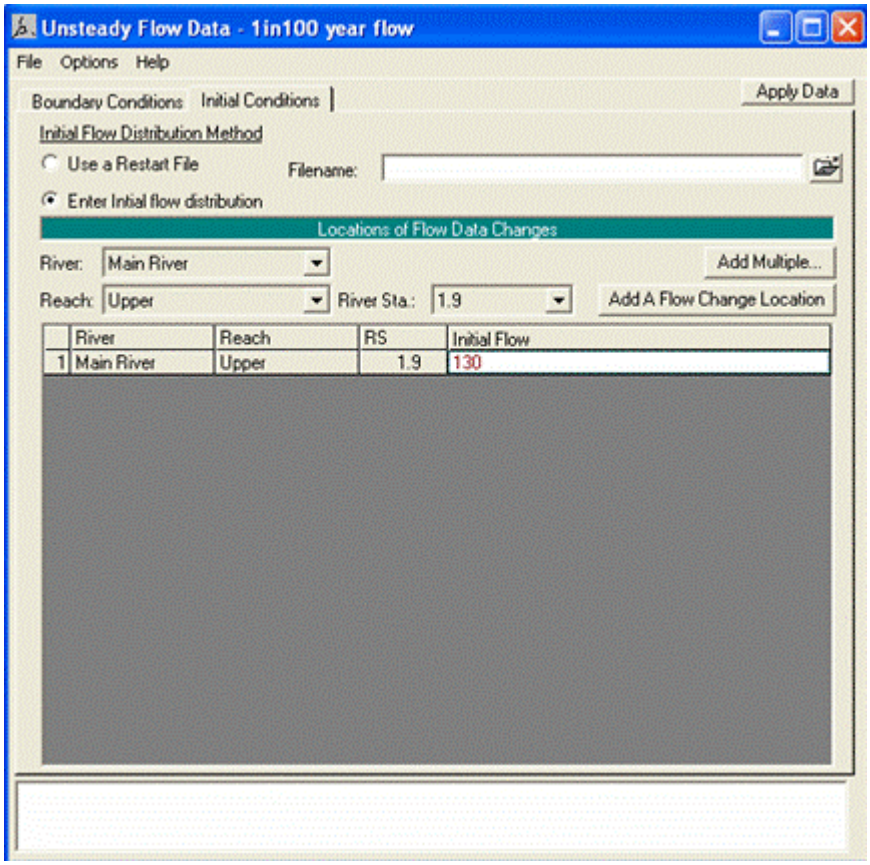


Figure 5 Initial flow editor

The first step is to put together a **Plan**. The Plan defines which geometry and flow data are to be used, as well as providing a title and short identifier for the run. To establish a plan, select **New Plan** from the **File** menu on the **Unsteady Flow Analysis** window. First open the Unsteady Flow Analysis window by going to the Run menu and selecting **Unsteady Flow Analysis**. Enter the plan title as "**1 in 100 year unsteady flow**" and then press the **OK** button. You will then be prompted to enter a short identifier. Enter a title of "**1in100Unstdy**" in the **Short ID** box.

The next step is to fill in the **Unsteady Flow Analysis Window** as shown in Figure 6. Now press the **Compute** button and the model should run.

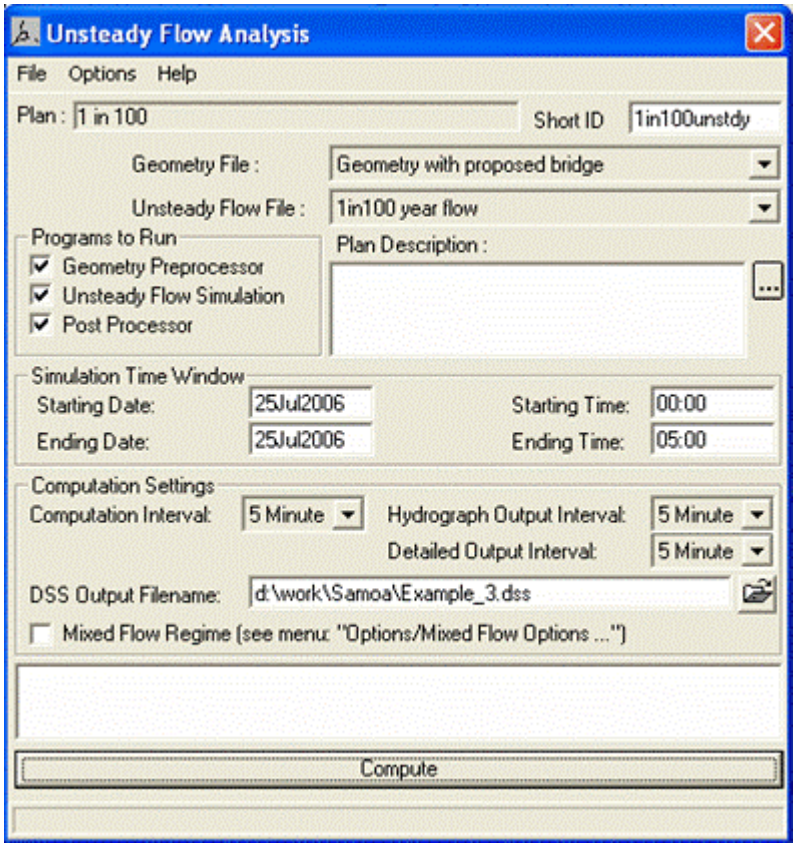


Figure 6 Unsteady Flow Analysis Simulation Window

Once the model has finished all of the computations successfully, you can begin viewing the results. Several output options are available from the **View** menu bar on the HEC RAS main window including:

- Create section plots;
- Profile plots;
- General plots;
- Rating curves;
- X-Y-Z perspective plots;
- Detailed tabular output at specific cross section (cross section table)
- Limited tabular output at many cross-sections.

Let's start by looking at Stage and Flow hydrographs. Go to the **View** menu and select **Stage and Flow Hydrographs**. Investigate the shape of the various water level and flow hydrographs for the different cross sections.

When you have done this go to the **View** menu and select **Water Surface Profiles**. Click on the black arrow and you will see an animation of how the water surface changes with time..

Next look at an X-Y-Z Perspective Plot of the river system. From the **View** menu bar on the HEC-RAS main menu, select **X-Y-Z Perspective Plots**. A multiple cross section perspective should appear on the screen. Try rotating the perspective view in different directions. Now press the black arrow and you should see an animation of how the water surface changes with time.

Now look at the tabular output. Go to the **View** menu bar on the HEC-RAS main window. There are two types of table available, a detailed output table and a profile summary table. Select **Detailed Output Tables** to get the first table to appear. This table shows detailed hydraulic information at a single cross sections.

Now bring up the profile summary table. This table shows a limited number of hydraulic variables for several cross sections. There are several types of profile tables listed under the **Std. Tables** menu bar of the profile table window. Some of the tables are designed to provide specific information at hydraulic structures (e.g. bridges and culverts), while others provide generic information at all cross sections. From the **View** menu select the **Profile Summary Table** option – make sure you select the **maximum water surface elevation**. Open a new Excel spreadsheet file. From the **File** menu in the Profile Output Table window select the **Copy to Clipboard (Data and Headings)** option. In the Excel spreadsheet you have opened select the paste options and save the spreadsheet as **Example_3_results.xls**.

Compare the maximum water levels from Exercise 2 running with a steady flow to those that you get from Exercise 3 with an unsteady flow hydrograph. What is the difference in maximum water levels directly upstream of the bridge for the 1 in 100 year flood between the unsteady and steady flow models?

You have now completed the third example.

Exercise 4 Running an unsteady flow model with the proposed bridge in place and an increase in the bed level caused by siltation

If the Example_3 project is not still open from your previous work re-open it. When you have re-opened it go to the **File** menu on the main window and select **Save Project As**. In the **Title** box enter "**Example 4 1 in 100 year with bridge with sediment"** and in the File Name box enter "**Example_4.prj**". Note it is important that you check under the **Options** menu that the **Unit System** is set to **SI** (i.e. Standard International or metric units).

The purpose of this exercise is to run the previous model you created with the proposed bridge with an unsteady flow and an increase in the river bed caused by the deposition of sediment.

The first step is to go to the **Edit** menu in the HEC RAS Main Window and select the **Geometric Data** editor. The **Geometric Data** editor shown should open. In the **Geometric Data** editor go to the **Tools** in the menu and select the **Fixed Sediment Elevations** option. A window similar to that shown in Figure 1 but without an increased in the bed level should open.

A geomorpholoigical study of the river has indicated that in ten years the upstream bed level at **River Station 1.9** will increase from **70.0 m to 71.5 m** and the downstream bed level will increase from **67.5 m to 70.0 m**. The purpose this exercise is to establish what effect this level of sedimentation will have on the 1 in 100 year flood levels.

In the **Fixed Sediment Elevation window** click on the **Interpolate** tab – see Figure 1. make sure you window looks *exactly* the same as Figure 1. The next step is to add the value of **71.5** in the **Upstream Elevation** box and the value of **70.0** in the **Downstream Elevation** box. Now click the **Apply Sediment Elevations to Selected Range** button. Now click on the **Update Plot** button. You will see the bed level increase as shown in Figure 1. Now click on the **OK** button. Now go to the **File** menu in the **Geometric Data** window and chose **Save Geometric Data As**. Save the new geometric data as "**Geometry with proposed bridge + sediment**".

The next step is to put together a **Plan**. The Plan defines which geometry and flow data are to be used, as well as providing a title and short identifier for the run. To establish a plan, select **New Plan** from the **File** menu on the **Unsteady Flow Analysis** window. First open the Unsteady Flow Analysis window by going to the Run menu and selecting **Unsteady Flow Analysis**. Enter the plan title as "**1 in 100 year flow with sediment**" and then press the **OK** button. You will then be prompted to enter a short identifier. Enter a title of "**Sediment**" in the **Short ID** box.

The next step is to fill in the **Unsteady Flow Analysis Window** as shown in Figure 2. Now press the **Compute** button and the model should run.

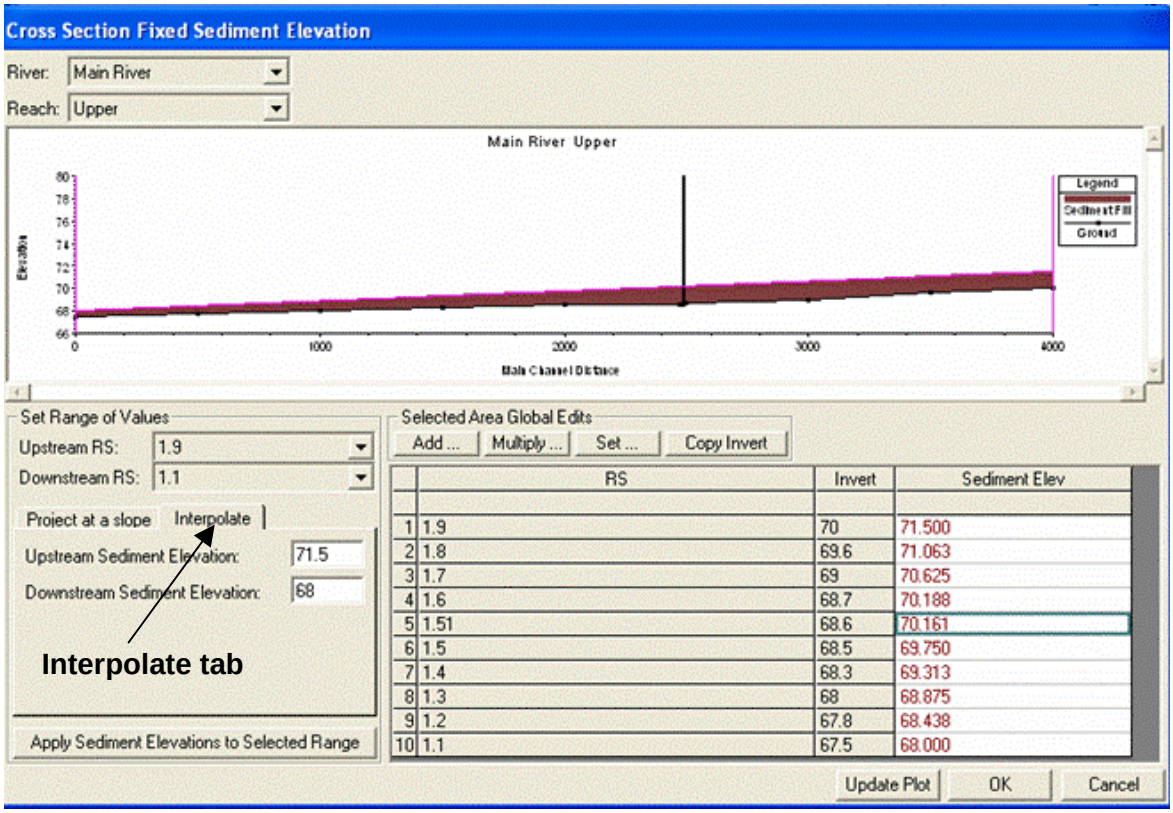


Figure 1 **Fixed sediment elevation window**

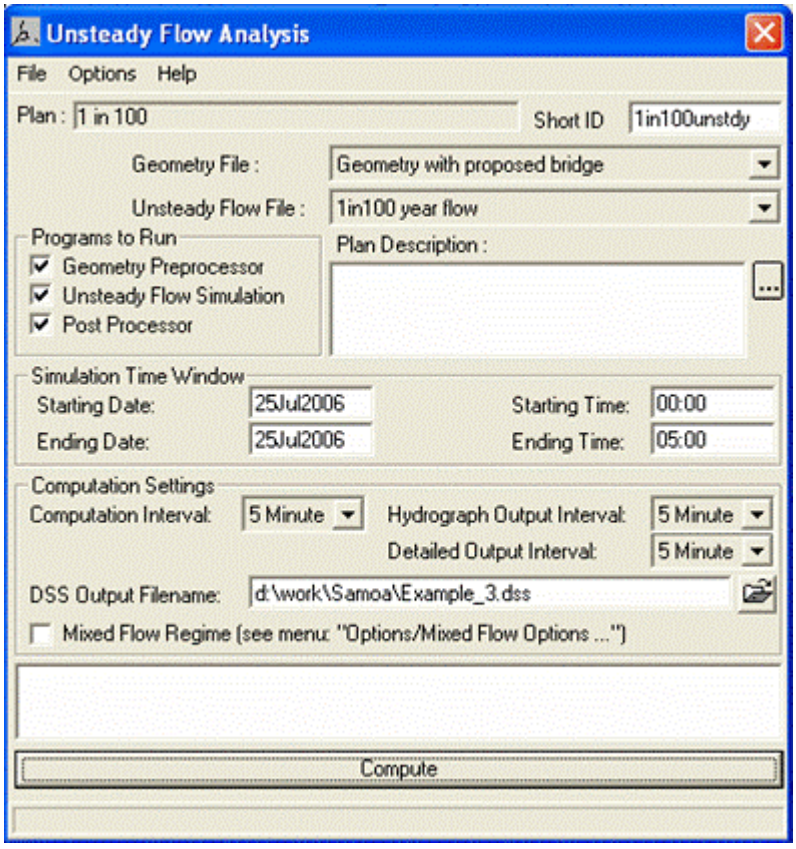


Figure 2 **Unsteady Flow Analysis Simulation Window**

Once the model has finished all of the computations successfully, you can begin viewing the results. Several output options are available from the **View** menu bar on the HEC RAS main window including:

- Create section plots;
- Profile plots;
- General plots;
- Rating curves;
- X-Y-Z perspective plots;
- Detailed tabular output at specific cross section (cross section table)
- Limited tabular output at many cross-sections.

Let's start by looking at Stage and Flow hydrographs. Go to the **View** menu and select **Stage and Flow Hydrographs**. Investigate the shape of the various water level and flow hydrographs for the different cross sections.

When you have done this go to the **View** menu and select **Water Surface Profiles**. Click on the black arrow and you will see an animation of how the water surface changes with time..

Next look at an X-Y-Z Perspective Plot of the river system. From the **View** menu bar on the HEC-RAS main menu, select **X-Y-Z Perspective Plots**. A multiple cross section perspective should appear on the screen. Try rotating the perspective view in different directions. Now press the black arrow and you should see an animation of how the water surface changes with time.

Now look at the tabular output. Go to the **View** menu bar on the HEC-RAS main window. There are two types of table available, a detailed output table and a profile summary table. Select **Detailed Output Tables** to get the first table to appear. This table shows detailed hydraulic information at a single cross sections.

Now bring up the profile summary table. This table shows a limited number of hydraulic variables for several cross sections. There are several types of profile tables listed under the **Std. Tables** menu bar of the profile table window. Some of the tables are designed to provide specific information at hydraulic structures (e.g. bridges and culverts), while others provide generic information at all cross sections. From the **View** menu select the **Profile Summary Table** option – make sure you select the **maximum water surface elevation**. Open a new Excel spreadsheet file. From the **File** menu in the Profile Output Table window select the **Copy to Clipboard (Data and Headings)** option. In the Excel spreadsheet you have opened select the paste options and save the spreadsheet as **Example_4_results.xls**.

Compare the maximum water levels from Exercise 3 running with an unsteady flow with no sediment to those that you get from Exercise 4 with an unsteady flow hydrograph and sediment. What is the difference in maximum water levels directly with and without sediment?

You have now completed the fourth example.

Exercise 5 Running an unsteady flow model with the proposed bridge in place, an increase in the bed level caused by siltation and an inline weir

If the Example_4 project is not still open from your previous work re-open it. When you have re-opened it go to the **File** menu on the main window and select **Save Project As**. In the **Title** box enter "**Example 5 1 in 100 year + bridge + sediment + weir"** and in the File Name box enter "**Example_5.prj**". Note it is important that you check under the **Options** menu that the **Unit System** is set to **SI** (i.e. Standard International or metric units).

The purpose of this exercise is to run the previous model you created with the proposed bridge with an unsteady flow, an increase in the river bed caused by the deposition of sediment and a ***new weir that is to be built upstream of the bridge***.

The first step is to go to the **Edit** menu in the HEC RAS Main Window and select the **Geometric Data** editor. The **Geometric Data** editor shown should open. In the **Geometric Data** editor go to the **Tools** in the menu and click on the **Inline Structure** button shown in Figure 1. A window similar to that shown in Figure 2 but without any data in it.

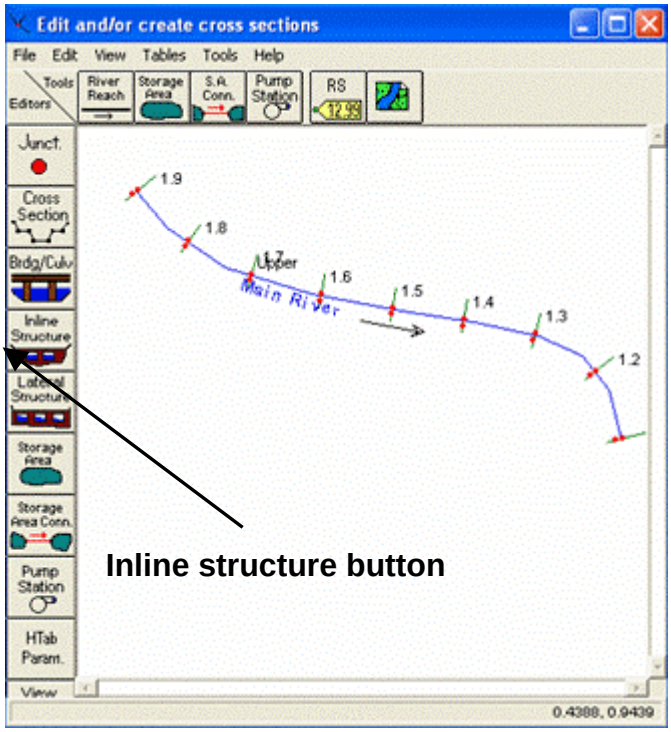


Figure 1 Geometric data window showing inline structure button

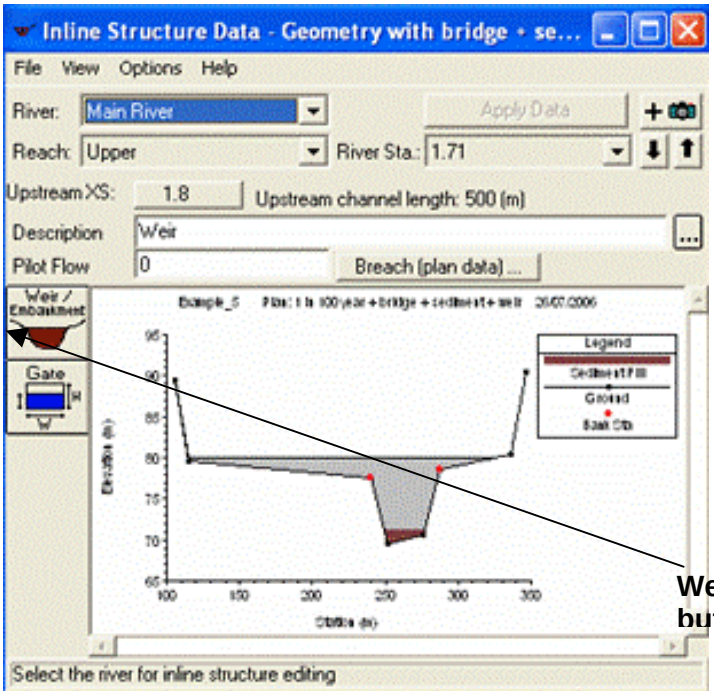


Figure 2 Inline structure window

In the **Inline Structure window** go to the **Options** menu and select **Add an Inline Structure** option. The popup box shown in Figure 3 should appear. Add a **River Station** of **1.71** in this popup box and change the **Pilot Flow** box from **0** to **10**.

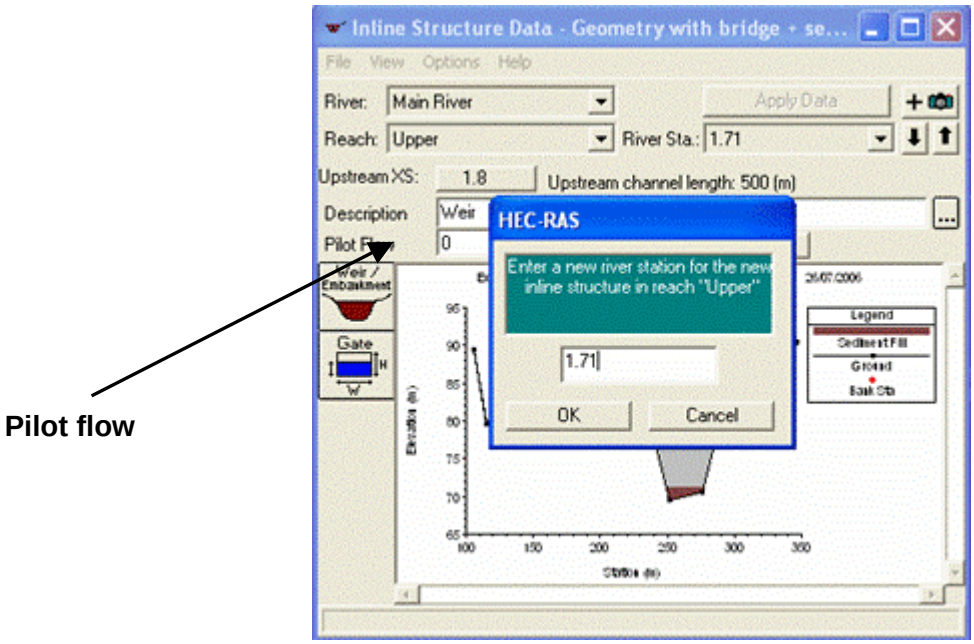


Figure 3 Popup box for entering the river station for an inline structure

Next click on the **Weir/Embankment** button shown in Figure 2. The window shown in Figure 4 should appear. Add the data shown in Figure 4 to your model so that it is ***exactly*** the same as shown in Figure 4.

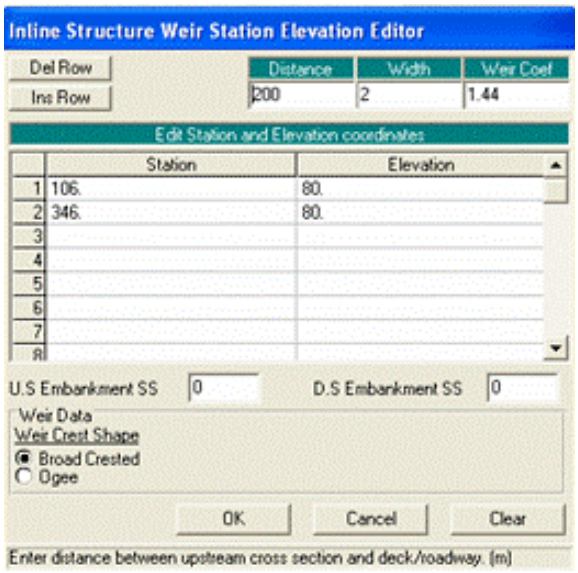


Figure 4 Inline structure weir station elevation editor

Once you have checked that this data is all correct go to the **File** menu in the **Geometric Data Window** and go to **Save Geometric Data As** "**Geometry with bridge + sediment + weir**".

The next step is to put together a **Plan**. The Plan defines which geometry and flow data are to be used, as well as providing a title and short identifier for the run. To establish a plan, select **New Plan** from the **File** menu on the **Unsteady Flow Analysis** window. First open the Unsteady Flow Analysis window by going to the Run menu and selecting **Unsteady Flow Analysis**. Enter the plan title as "**1 in 100 + bridge + sediment + weir**" and then press the **OK** button. You will then be prompted to enter a short identifier. Enter a title of "**100Weir**" in the **Short ID** box.

The next step is to fill in the **Unsteady Flow Analysis Window** as shown in Figure 5. NOTE: *The Geometry file and short ID will be different from that shown in Figure 5*. Now press the **Compute** button and the model should run.

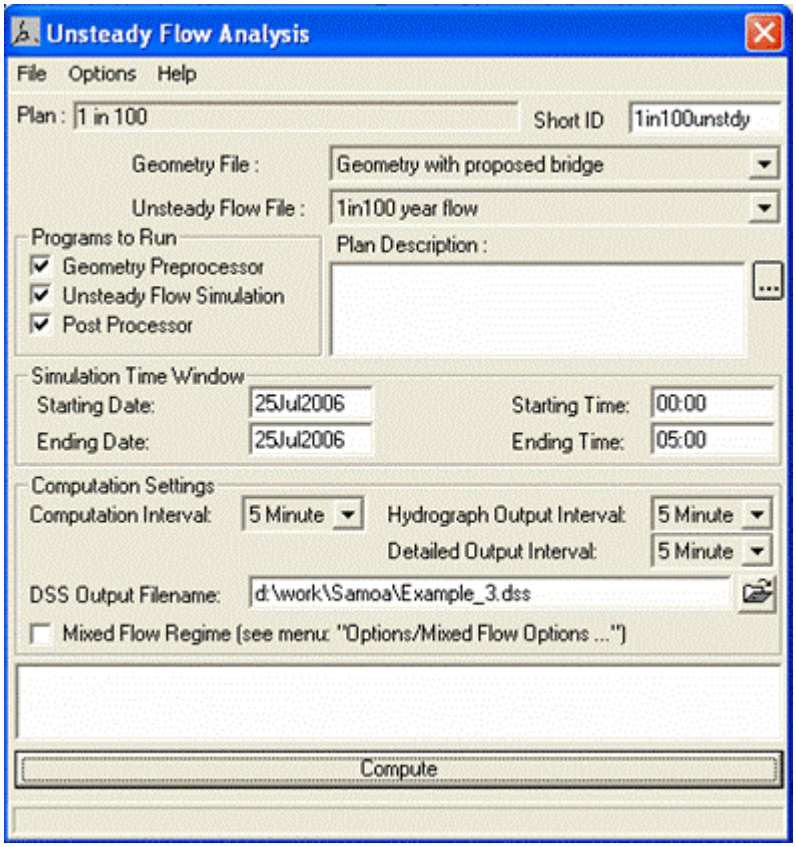


Figure 5 Unsteady Flow Analysis Simulation Window

Once the model has finished all of the computations successfully, you can begin viewing the results. Several output options are available from the **View** menu bar on the HEC RAS main window including:

- Create section plots;
- Profile plots;
- General plots;
- Rating curves;
- X-Y-Z perspective plots;
- Detailed tabular output at specific cross section (cross section table)
- Limited tabular output at many cross-sections.

Let's start by looking at Stage and Flow hydrographs. Go to the **View** menu and select **Stage and Flow Hydrographs**. Investigate the shape of the various water level and flow hydrographs for the different cross sections.

When you have done this go to the **View** menu and select **Water Surface Profiles**. Click on the black arrow and you will see an animation of how the water surface changes with time..

Next look at an X-Y-Z Perspective Plot of the river system. From the **View** menu bar on the HEC-RAS main menu, select **X-Y-Z Perspective Plots**. A multiple cross section perspective should appear on the screen. Try rotating the perspective view in different directions. Now press the black arrow and you should see an animation of how the water surface changes with time.

Now look at the tabular output. Go to the **View** menu bar on the HEC-RAS main window. There are two types of table available, a detailed output table and a profile summary table. Select **Detailed Output Tables** to get the first table to appear. This table shows detailed hydraulic information at a single cross sections.

Now bring up the profile summary table. This table shows a limited number of hydraulic variables for several cross sections. There are several types of profile tables listed under the **Std. Tables** menu bar of the profile table window. Some of the tables are designed to provide specific information at hydraulic structures (e.g. bridges and culverts), while others provide generic information at all cross sections. From the **View** menu select the **Profile Summary Table** option – make sure you select the **maximum water surface elevation**. Open a new Excel spreadsheet file. From the **File** menu in the Profile Output Table window select the **Copy to Clipboard (Data and Headings)** option. In the Excel spreadsheet you have opened select the paste options and save the spreadsheet as **Example_5_results.xls**.

Compare the maximum water levels from Exercise 4 running with an unsteady flow with no sediment to those that you get from Exercise 5 with an unsteady flow hydrograph and sediment. What is the difference in maximum water levels directly with and without the weir in place?

You have now completed the fifth example.

APPENDIX G

Glossary of Terms

Appendix G Glossary of Terms

GLOSSARY OF TERMS

Accuracy	Closeness to reality.
Bankfull capacity	The flow carried by a river at its bankfull water level.
Basin (river)	The area from which water runs off to a given river (see catchment).
Calibration	Adjustment of a model to reach an acceptable degree of accuracy.
Catchment	The area of land draining to a specific location. It includes the catchments of tributaries as well as the main river.
Consequence	An impact such as economic, social or environmental damage/improvement that may result from a flood. It can be expressed quantitatively (e.g. monetary value), by category (e.g. High, Medium, Low) or descriptively.
Conveyance	Measure of the discharge carrying capacity of a channel K m^3/s at a given depth and slope.
Culverts	Pipes to enable the flow of water between catchments where roads and railways traverse watersheds.
Design flood	The flood adopted for the design of a structure (e.g. culvert, bridge, flood wall).
Deterministic approach	Using observations to produce theories, as opposed to probabilistic approaches, which design theories then test using observations.
Discharge	The rate of flow of water, as measured in terms of volume per unit time, for example cubic metres per second (m^3/s)
Emergent vegetation	Plants growing above water but that are rooted below the surface or along the water edge.
Empirical formulae	Formulae derived from field or experimental data.
Error	Mistaken calculations or measurements with quantifiable and predictable differences.
Exceedence probabilities	The probability that a flood will be greater than a set limit.
Extrapolation	Extension of a relationship beyond the limits of observations.
Flash flooding	Sudden and unexpected flooding caused by local heavy rainfall or rainfall in another area.

Flood	A temporary 'unwanted' covering of land by water.
Flood damage	Damage to receptors (buildings, infrastructure, goods), production and intangibles (life, cultural and ecological assets).
Flood forecasting system	A system designed to provide a forecast of flood levels before they occur.
Flood frequency	The probability, expressed as a percentage, that a flood of a given size will be equalled or exceeded in any given year. A statistical expression or measure of the average time period between floods equalling or exceeding a given magnitude (See Return Period).
Flood hazard map	A map with the predicted or documented extent of flooding, with or without an indication of the flood probability.
Flood level	Water level during a flood.
Floodplain	Area of land adjacent to a river, estuary or coast which is subject to inundation by flooding.
Flood risk	Flood risk is defined as: (Probability of flooding) x (Consequence of flooding) Flood risk is normally measured in terms of economic damages for a particular probability of flooding, or Annual Average Damages based on the full range of floods that could occur.
Flood study	A comprehensive technical investigation of flood behaviour.
Fluvial	Relating to rivers.
Freeboard	The height above a defined flood level typically used to provide a factor of safety in, for example, the setting of floor levels and embankment crest levels.
Hazard	A physical event, phenomenon or human activity with the *potential* to result in harm. A hazard does not necessarily lead to harm.
Hazard mapping	The process of establishing the spatial extents of hazardous phenomena.
Heterogeneity	Similarity e.g. heterogeneous catchments will have similar characteristics.
Hydrograph	A graph that shows for a particular location, the variation with time of discharge (discharge hydrograph) or water level (stage hydrograph) during the course of a flood.

Hydrometeorology	Specialist branch of hydrology: the study of precipitation and evaporation**.**
Interpolation	Estimation of values based on a relationship within the limits of observations.
Inundation	Flooding of land with water.
Iteration	Process of refining a value to an acceptable level of accuracy, by using the output of one calculation as input to the next.
Pathway	Route that a hazard takes to reach Receptors. A pathway must exist for a Hazard to be realised.
Peak discharge	The maximum discharge occurring during a flood event past a given point on a river system.
Precision	The degree of exactness regardless of accuracy.
Rating curve	Relationship between water depth and discharge at a particular point on a river.
Receptor	Receptor refers to the entity that may be harmed (e.g. a person, property, habitat etc.). For example, in the event of heavy rainfall (the source) flood water may propagate across the flood plain (the pathway) and inundate housing (the receptor) that may suffer material damage (the harm or consequence). The vulnerability of a receptor can be modified by increasing its resilience to flooding.
Regression	Mathematical analysis of applying straight line principles to an observed relationship.
Resistance	Impedance of normal water flow, defined as flow-, form-, frictional, turbulent etc.
Return period	The expected (mean) time (usually in years) between the exceedence of a particular extreme threshold. Return period is traditionally used to express the frequency of occurrence of an event, although it is often misunderstood as being a probability of occurrence.
Risk	Risk is a function of probability, exposure and vulnerability. Often, in practice, exposure is incorporated in the assessment of consequences, therefore risk can be considered as having two components — the probability that an event will occur and the impact (or consequence) associated with that event. Risk = probability x consequence.

Risk mapping	The process of establishing the spatial extent of risk (combining information on probability and consequences). Risk mapping requires combining maps of hazards and vulnerabilities. The results of these analyses are usually presented in the form of maps that show the magnitude and nature of the risk.
Roughness	The effect of impeding the normal water flow of a channel by the presence of a natural or artificial body or bodies, bed substrate, biotic e.g. vegetation, or abiotic/mineral e.g. bank.
Runoff	The amount of rainfall that drains into the surface drainage network to become stream flow.
Scenario	A plausible description of a situation, based on a coherent and internally consistent set of assumptions. Scenarios are neither predictions nor forecasts. The results of scenarios (unlike forecasts) depend on the boundary conditions of the scenario.
Source	The origin of a hazard (for example for a flood it may be heavy rainfall, strong winds, tidal surge etc).
Stage	Equivalent to "water level". Both are measured relative to a specified datum.
Steady flow	A flow in which the magnitude and direction of the specific discharge are constant in time.
Stakeholders	Parties/persons with a direct interest (stake) in an issue.
Stream power	Rate of work required by a river to transport water and sediment.
Surge conditions	Astronomic tide plus storm surge water levels.
Trash screens	Screens in front of structures where rubbish is collected for removal
T-year flood	Flood with a return interval (the length of time between floods exceeding given magnitude) of T years.
Uncertainty	A general concept that reflects our lack of sureness about someone or something, ranging from just short of complete sureness to an almost complete lack of conviction about an outcome.
Unit hydrograph	Deterministic technique for relating rainfall to runoff. The response of a catchment to a unit depth (usually 1 cm) of effective rainfall in a unit time.